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NRCS CURVE NUMBER CALIBRATION USING USGS REGRESSION EQUATIONS

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NRCS CURVE NUMBER CALIBRATION

USING USGS REGRESSION EQUATIONS

by

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GRADUATE COMMITTEE APPROVAL

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BRIGHAM YOUNG UNIVERSITY

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ABSTRACT

NRCS CURVE NUMBER CALIBRATION

USING USGS REGRESSION EQUATIONS

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Master of Science

The Curve Number (CN) method of estimating the direct runoff response to rainfall events was originally developed in the 1950's primarily for agricultural purposes in the mid-western United States. The accuracy of the CN method is greatly affected by variation in soil type and land use of the region. Curve Numbers developed for a given region are not appropriate for application in other regions. In order to produce reliable, consistent results, Curve Numbers must be calibrated for the area where the CN method is to be applied.

Calibration is ideally accomplished by direct measurement using several rain and stream gauges within a watershed. Gauged data, however, is not always available or easily obtained. A more feasible method of calibration is therefore necessary for broad application of the CN method.

The purpose of this study is to develop a method of CN calibration that can be easily applied to regions where no gauged data is available using the United States Geological Survey (USGS) regression equations. In this study, the peak flow values estimated using the regression equations were used in conjunction with an average hydrograph to compute runoff volume. The National Oceanic and Atmospheric Administration (NOAA) rainfall grids were used to estimate precipitation. Given the rainfall and runoff, a Curve Number can then calibrated through back-calculation.

The method of CN calibration using the USGS regression equations was applied to nearly 60 watersheds in the state of Utah for this research. The calibration results obtained using the regression equations were compared to other CN calibrations developed using gauged data. Calibrations performed through the use of the regression equations were quite consistent with calibrations obtained using measured data. To ensure the validity of the application of this method in other regions, more comparisons to results obtained using measured data should be further pursued

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 Introduction

An accurate understanding of surface hydrology is a critical element in the design roads, bridges, culverts, and other structures. The ability to predict and design for future rainfall and surface runoff volumes is not only helpful in ensuring adequate drainage capacity of these structures, but also economically important. Predictions of runoff volume that are too high could result in the over-design of the structure and thus, unnecessary expenditures. Predictions that are too low could result in catastrophic damages to the structure and costly repairs.

Several methods for estimating the rainfall-runoff relationship have been developed to assist in the appropriate design of these types of structures. One of the more common and widely used methods is the Curve Number (CN) method (Hawkins *et al.*, 2006). The CN method was developed in the mid-1950's by the Soil Conservation Service (SCS) now known as the Natural Resources Conservation Service (NRCS) in effort to provide a consistent and objective method for relating rainfall to runoff primarily for agricultural purposes in the mid-western United States (USDA, 1985). The application of the CN method has since been extended beyond the original intent of use within small agricultural watersheds. In actual use by government agencies and practicing engineers, most Curve Numbers are drawn from agency tables derived from CN tables originally developed for Midwestern agriculture or from consensus tables agreed upon for local usage (Hawkins *et al.*, 2006). The Curve Number method is highly sensitive to the selected CN. If the CN is selected from tables derived for another region, it is possible that the CN and predicted runoff volume would be inaccurate given the local conditions, and would result in over or under-design. For the CN method to provide users with consistent data, local calibration of CN values is needed.

CN calibration is ideally performed by direct measurement using observed rain and stream gauge data. While this method is ideal, it is difficult to accomplish. Retrieving enough usable observed rain and stream gauge data in order to produce an accurate calibration is time consuming and often not possible. The Utah Department of Transportation (UDOT) is frequently involved with projects and hydrological studies throughout the state of Utah. While it may be possible for UDOT or other organizations to use existing networks of National Oceanic and Atmospheric Administration (NOAA) rain gauges and United States Geologic Survey (USGS) flow stations, in many cases, the project site is not located near any rain or stream gauges. Thus direct CN calibration measures are frequently unachievable. A more feasible method of calibration is necessary for broad use of the CN method in ungauged regions.

Due to the unavailability and difficulty in obtaining observed data, the USGS has developed regional regression equations for estimating flood magnitude and frequency at ungauged sites. These regression equations are used to interpolate or transfer flood characteristics from gauged to ungauged sites through the use of watershed and climatic characteristics including area, channel characteristics, elevation, and mean annual precipitation among others. These equations have been developed on a state-by-state basis for hydrologically similar regions. In 1994, the USGS developed a computer program called the National Flood Frequency Program (NFF). All of the regression equations were compiled into a database for use in this program, which is often used by engineers and accepted by the Federal Highway Administration (FHWA) and Federal Emergency Management Agency (FEMA) for planning and design applications (Reis *et al*., 2002). Use of the USGS regression equations is a viable and practical substitute for obtaining real data given its foundation in historical gauged data.

In order to perform CN calibration, the rainfall depth and associated runoff depth must be known for a given storm event in a given watershed. For the method of calibration developed in this study, the peak runoff flow predicted using the USGS regression equations are indexed by return-period and used in conjunction with a unit hydrograph to compute the total runoff volume for each return-period. By dividing by the area of the watershed in question, runoff volume can be converted to an average runoff depth. Rainfall grids provided by NOAA are used to estimate the precipitation depth by return-period. Given the rainfall and runoff depth, a site-specific CN can then be calibrated for each return-period. A request from UDOT for a locally calibrated CN table was the impetus of this research. Calibration of the CN table currently used by UDOT has been performed using the regression equations and will be used as an illustration of this process.

The purpose of this study is to develop a method of CN calibration that can be easily applied to regions where gauged data are unavailable using the USGS regression equations. In this study, regression equation calibration was performed for nearly 60 watersheds throughout the state of Utah. The calibration results from these watersheds have been investigated for regional trends and have been compared to calibration results that were obtained using measured rain and stream gauge data. While much of this research has been focused on watersheds within the state of Utah, this method can be applied to any location where flood regionalization studies have been performed and regression equations are available. Calibration results obtained through the use of the USGS regression equations appear consistent with results obtained from gauged data. CN calibration performed through using the regression equations can potentially enable engineers and other organizations to more easily calibrate CN tables for local conditions and improve the adequacy of their designs.

2 Background

The CN method, USGS regression equations, design hydrographs and NOAA rainfall grids are all quite commonly used in engineering practice. CN calibration using the regression equations combines many of these engineering tools. To clarify these concepts, a background of the CN method, the USGS regression equations and design hydrographs is given.

2.1 Curve Number Method

There are many factors that influence the infiltration and runoff volume within a watershed including the intensity of the storm, the volume of precipitation, the land use (i.e. forested, residential, etc.), soil type (i.e. clay, sand, etc.) and initial moisture conditions (i.e. wet, dry, etc.). The CN method is empirical in nature and based on land use, soil type and antecedent moisture conditions. The following is an overview and explanation of the Curve Number method.

2.1.1 Curve Number Method Derivation

At the beginning of a rainfall event, the rainfall intensity is usually less than the rate at which water is stored, meaning all the precipitation is absorbed into the soil. However, as the storage is filled, and the soil and vegetation become saturated, there is less capacity for storage or absorption. The precipitation is in excess and begins to "runoff" the land surface into streams, rivers and lakes. If the land is well forested, the rainfall is readily absorbed by the vegetation. However, if the land is paved as it is in a residential area, there is little absorption and nearly all precipitation becomes direct runoff. Water flows more freely through sand than through clay thus precipitation is absorbed by sand but flows across the top of a clay surface. If the soil is initially saturated from a previous event, there is less storage capacity and most of the precipitation from the event following will become runoff (Wanielista *et al.*, 1997, 153).

In general terms runoff is represented by the following equation:

$$R = P - S \tag{2-1}$$

where R = rainfall excess or runoff (in)

P= rainfall volume (in)

S= storage volume including initial abstraction and infiltration (in)

Initial abstraction is water intercepted by vegetation and stored in surface depressions (Wanielista *et al.*, 1997, 8). At saturation, the rate of rainfall excess is equal to the intensity of precipitation. A proportional relationship can be developed as:

$$\frac{S}{S'} = \frac{R}{P} \tag{2-2}$$

where S'= Storage at saturation (in)

The relationship of these factors is illustrated below in Figure 2-1.

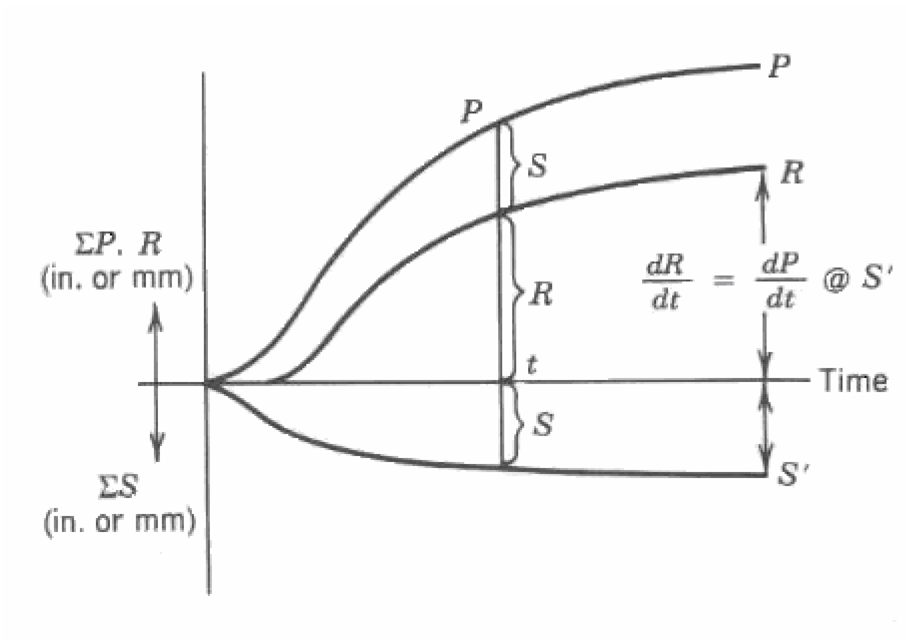


Figure 2-1: Time Variability of Hydrologic Events (Wanielista *et al.*, 1997, 153)

Rearranging and then inserting Equation 2-1 into Equation 2-2 results in the following:

$$\frac{(P-R)}{S'}=\frac{R}{P}$$

Additional work done by the SCS identified an empirical relationship between the initial abstraction (I_a) and storage and developed an equation where I_a is defined as 0.2S'. However, abstraction values vary for different soil types. The empirical equations developed by the SCS to estimate maximum water storage capacity and rainfall excess are estimated using the equations below.

$$S' = \frac{1000}{CN} - 10 \qquad \text{(in)} \tag{2-3}$$

$$R = \frac{(P - 0.2S')^2}{(P + 0.8S')} \qquad \text{(in)} \tag{2-4}$$

$$\text{if} \quad P \geq 0.2S' \text{ otherwise } R = 0$$

A graph of this equation is shown in Figure 2-2 below:

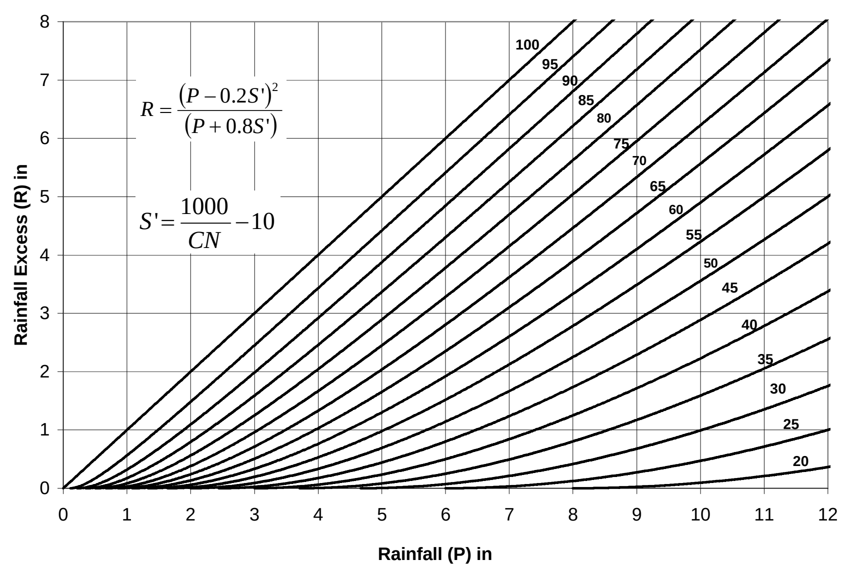


Figure 2-2: Curve Number on Rainfall vs. Rainfall Excess Plot (Wanielista *et al.*, 1997, 160)

2.1.2 Curve Number Affecting Factors

Three factors that affect the CN value are antecedent moisture condition, soil type, land use.

Antecedent Moisture Conditions

The NRCS has established three antecedent moisture conditions. These conditions are as follows:

- Condition 1:

  A condition of drainage basin soils where the soils are dry but not to wilting point

- Condition 2:

  The average case

- Condition 3:

  When heavy rainfall or light rainfall with low temperatures have occurred, producing high runoff potential.

Most CN tables are developed for Condition 2, the average case. However, there are adjustment factors available for Conditions 1 and 3 (Wanielista *et al.* 1997, 154).

Soil Type

The soil type is divided into four classes, A through D based on the ability of water to pass through the soil which is identified as the transmission rate as follows:

Table 2-1: Soil Type Classifications Based on Transmission Rate of Water (Hawkins et al., 2006)

Group	Soil Type	Tranmission rate (in/hr)
A	Sand, loamy sand, sandy loam	greater than 0.30
B	Silt loam or loam	0.15 to 0.30
C	Sandy clay loam	0.05 to 0.15
D	Clay	0 to 0.05

Land Use

As stated previously, land that is well forested readily absorbs rainfall whereas in areas that are covered with impervious surfaces such as pavement, nearly all precipitation becomes direct runoff. The variation in the CN due to land use can be seen in the CN table shown below in Table 2-2 which was developed for antecedent moisture condition II. Variation in the CN due to soil type is found under the "Hydrologic Soil Group" column.

Table 2-2: CN Table (TR-55 1985)

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

1 Average runoff condition, and $I_a = 0.2S$.
2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.
3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.
4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.
5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

As can be seen, the CN is very dependent upon local conditions. Local conditions should be taken into careful consideration when using the CN Method in order to avoid inaccurate runoff estimations.

2.1.3 CN Back-Calculation Derivation

Typically, the CN method is used to estimate runoff, however, if the rainfall and runoff is known, a CN for a particular watershed and storm event can be back-calculated. The derivation of this procedure is as follows. Rearranging Equation 2-3, we can solve for CN:

$$S' = \frac{1000}{CN} - 10 \qquad \textbf{(2-5)}$$

$$CN = \frac{1000}{S'+10}$$

We can rearrange Equation 2-4, insert it into the quadratic equation to solve for S' in terms of R and P:

$$R = \frac{(P - 0.2S')^2}{(P + 0.8S')} \qquad \textbf{(2-6)}$$

$$R(P + 0.8S') = (P - 0.2S')^2$$

$$PR + 0.8S'R = P^2 - 0.4S'P + 0.04S'^2$$

$$0 = 0.04S'^2 - 0.4S'P - 0.8S'R + P^2 - PR$$

$$0 = S'^2 - 10S'P - 20S'R + 25P^2 - 25PR$$

$$0 = S'^2 - 10S'(P + 2R) + 25P^2 - 25PR$$

The general form of the quadratic equation is:

$$y = \frac{-b + or - \sqrt{b^2 - 4ac}}{2a}$$

where

$$0 = ay^2 + by + c$$

In this case,

$$\begin{aligned} y &= S' \\ a &= 1 \\ b &= -10P - 20R \\ c &= 25P^2 - 25PR \end{aligned}$$

$$S' = \frac{-(-10P - 20R) \pm \sqrt{(-10P - 20R)^2 - 4(1)(25P^2 - 25PR)}}{2(1)}$$

$$S' = \frac{10P + 20R \pm \sqrt{100P^2 + 400PR + 400R^2 - 100P^2 + 100PR}}{2}$$

$$S' = 5(P + 2R) \pm 5\sqrt{5PR + 4R^2}$$

After having solved for S’ in terms of R and P, we can solve for CN in terms of R and P:

$$CN = \frac{1000}{S'+10}$$

$$CN = \frac{1000}{5(P+2R) - 5\sqrt{5PR+4R^2} + 10}$$

$$CN = \frac{200}{P+2R-\sqrt{5PR+4R^2}+2} \quad \textbf{(2-7)}$$

The negative root is selected in order to obtain the correct solution for Equation 2-5 (Curtis et. al. 2, 1983).

2.2 USGS Regional Regression Equations

The USGS has developed regional regression equations which are used to transfer flood characteristics from gauged to ungauged sites. These equations aid engineers in the design of projects where gauged rainfall and runoff data is unavailable. The regression equations have been developed on a regional basis and were compiled into a database which is used in a computer program called the National Flood Frequency Program (NFF) (Reis et al., 2002). The concept of expanding the utility of gauged site data for use at ungauged locations with similar physiographic and climatic characteristics is not new, and several methods have been examined and tested during the past 50 years. The method of choice for the past 30 years has been statistically based regional equations that predict peak stream flow. This method involves a division of the study area into regions of similar physiographic and climatic characteristics.

2.2.1 Flood Regionalization

The testing of regional homogeneity is a critical part of flood regionalization procedures due to the substantial variability of flood characteristics that may exist between regions with differences in climate, topography, and geology. Multiple-linear regression techniques are applied to determine coefficients for statistically significant predictors of peak stream flow i.e. basin area, elevation, and mean annual precipitation. Upon determining the level of influence these variables have on peak stream flow, regression equations can then be derived accordingly (USGS 1999).

2.2.2 Return-Period

For every region, regression models or equations are developed for each return period or recurrence interval flow such as the 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year peak flow. A return-period or recurrence-interval is an estimate of the likelihood of events. It is a statistical measurement indicating the average recurrence interval over an extended period of time. A specified return-period is usually required for risk analysis in order to design structures so that they are capable of withstanding an event of a certain return-period and its associated intensity (USGS 1999).

2.2.3 Design Hydrograph Development

A runoff hydrograph is defined as an expression for surface water discharge over time. A runoff hydrograph has three main parts: a rising limb, peak discharge and a falling limb. The area under the hydrograph represents the total volume of runoff in a watershed during a storm event. The variation of hydrograph shape is due to varying storm intensity over time and unique watershed characteristics (Wanielista *et al.* 1997, 205). A hydrograph for a single storm event is shown below in Figure 2-3.

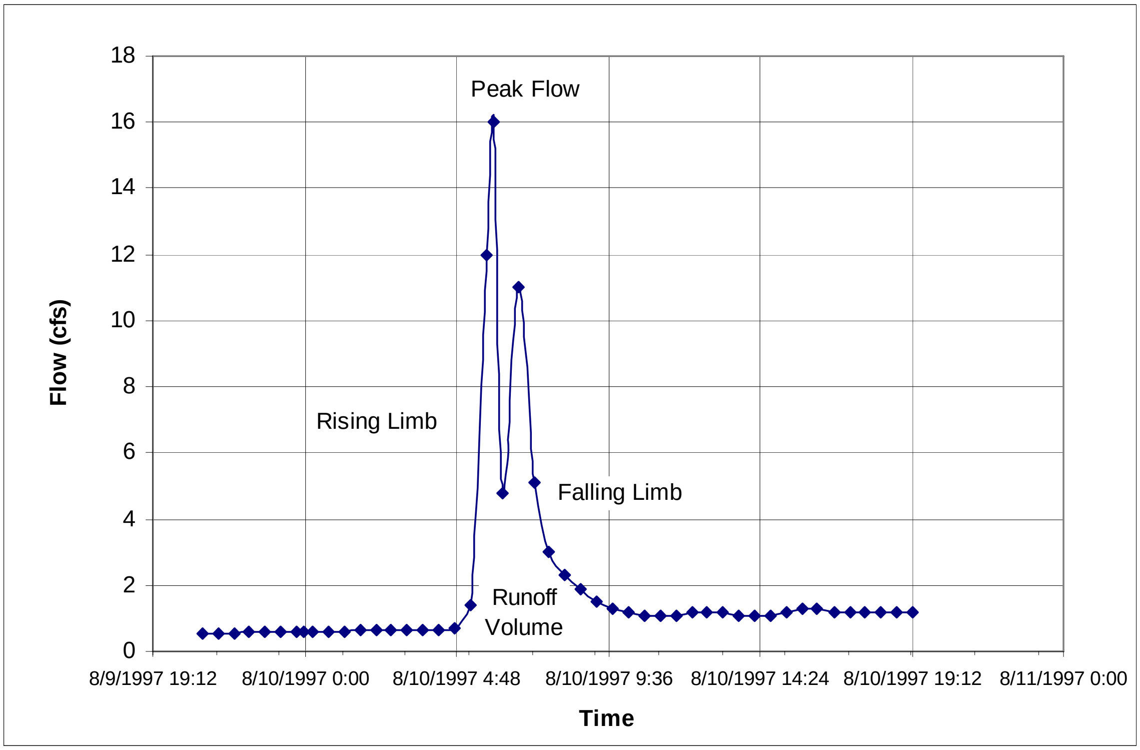


Figure 2-3: Runoff Hydrograph for a Single Storm Event (Williams 2005)

The hydrograph in Figure 2-3 features a double peak. Multiple peaks are common in hydrographs that depict a naturally occurring storm event. Often the intensity of the storm and consequently the runoff will vary over the duration of the storm.

The use of “synthetic” or hydrographs is very common in engineering practice. A synthetic hydrograph is a hydrograph that does not represent runoff from an actual storm, but is a typical or average hydrograph. The hydrographs that are used in this study are synthetic and do not represent any particular rainfall distribution but are useful for design applications where runoff volume needs to be estimated. The peak flows calculated using regression equations are used in conjunction with a dimensionless unit hydrograph to produce a design hydrograph. The unit hydrograph is defined as a hydrograph of direct runoff resulting from 1 inch of effective rainfall uniformly generated over the basin at a uniform rate for a specified time period or duration. The following basic assumptions apply to the unit hydrograph:

- The effective rainfall is uniformly distributed within its duration.
- The effective rainfall is uniformly distributed throughout the entire basin.
- The base or time duration is constant.
- The ordinates of the direct-runoff hydrograph are directly proportional to the total amount of direct runoff represented by each resulting hydrograph.
- The hydrograph reflects all the physical characteristics of the given basin.

Three essential elements are needed in order to develop a design including:

1. the peak discharge
2. the basin lag time

3. the dimensionless hydrograph ordinates

Using NFF, after the peak flow is determined for a specified return-period using the regression equations, a basin lag time must be estimated. NFF then computes a hydrograph based on the dimensionless ordinates which are stored in the program (FEMA 2007). Figure 2-4 depicts design hydrographs of multiple return-periods for a given watershed.

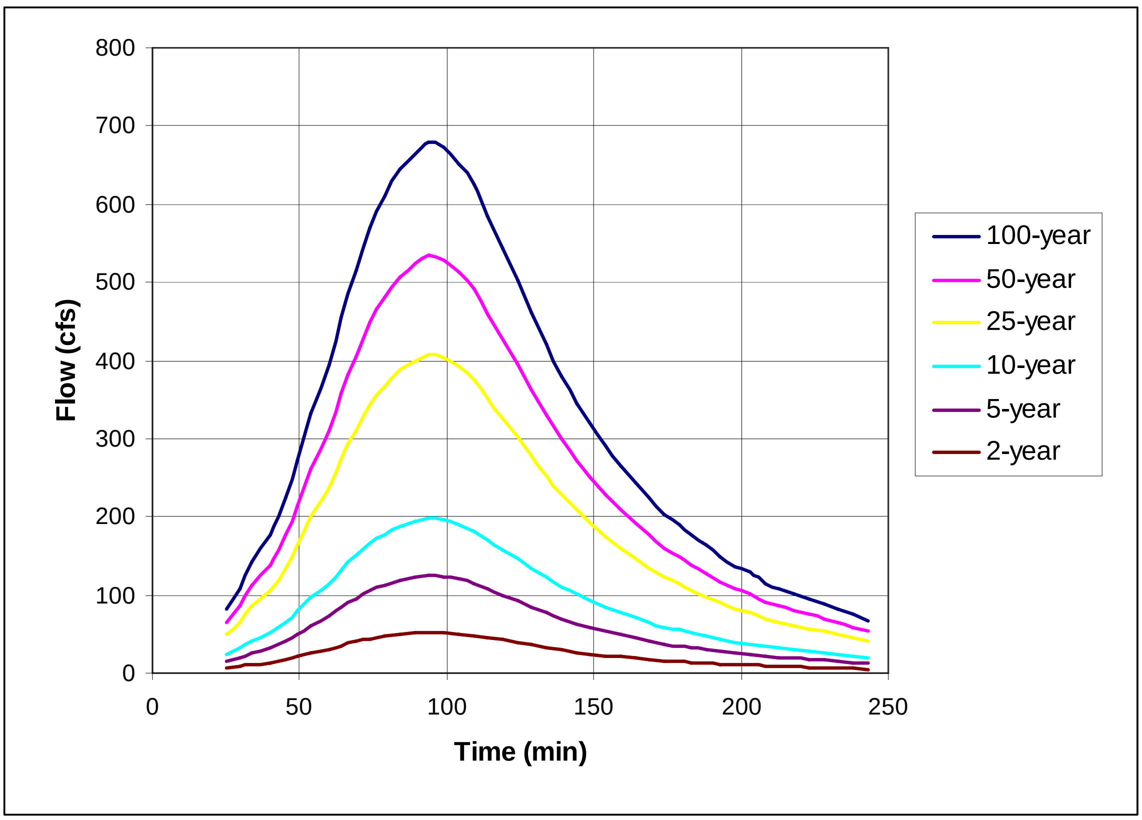


Figure 2-4: Hydrograph by Return-Period Developed using NFF

Unlike the hydrograph shown in Figure 2-3, the design hydrograph produced by NFF features only a single peak. While the hydrographs shown in Figure 2-4 do not depict actual storm events, they are based on historical data and estimate the volume of flow for each return-period based on the peak flow and watershed lag time, which is useful for some design purposes.

2.2.4 Utah USGS Regression Equations

The state of Utah is located within a regional flood study area that encompasses the arid lands of the southwestern United States. The study area is divided into 16 hydrologic flood regions, of which 7 include portions of Utah. A map of these regions is shown in Figure 2-5. Within Utah, regions with an elevation greater than a specified threshold are considered to be in Region 1 (see Figure 2-6). While the use of regression equations is a convenient method for runoff estimation, there are, however, limitations in applicability. The Table 2-3 summarizes these limitations by region.

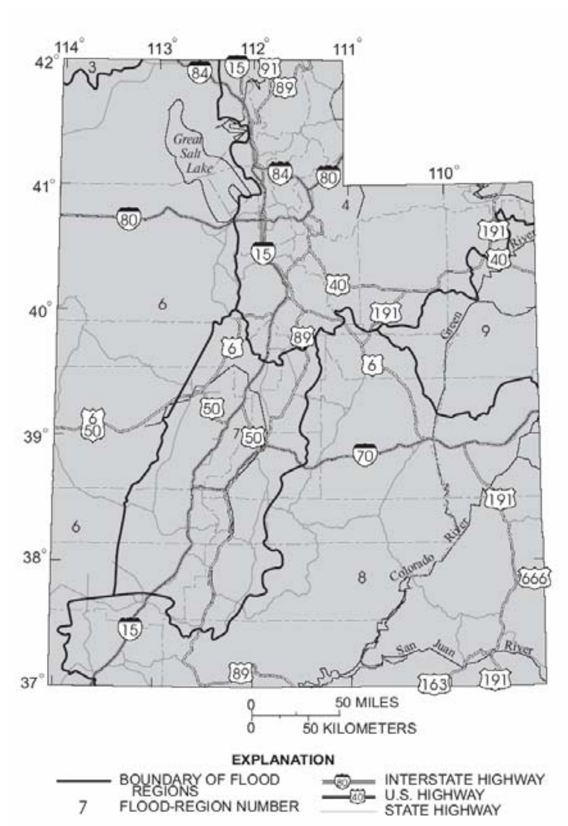


Figure 2-5: NFF Regions in Utah (USGS 1999)

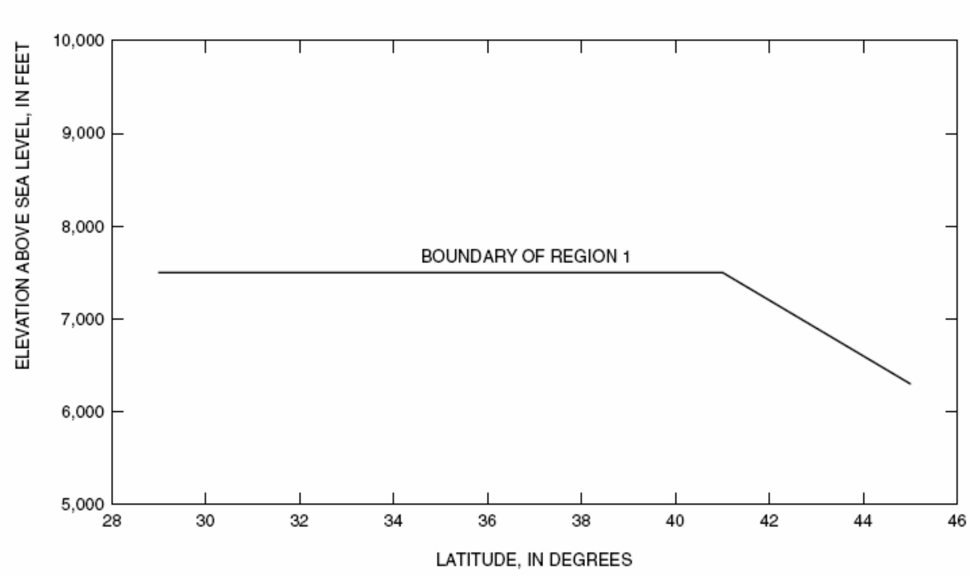


Figure 2-6: Utah NFF Region 1 Elevation Threshold (USGS 1999)

Table 2-3: Limitations in Regression Equation Applicability (USGS 1999)

Hydrologic study region	Drainage area, in square miles[1]	Mean basin elevation, in feet above sea level[2]	Mean annual precipitation, in inches
Region 1	0.30–1,060[1]	--	10–45
Region 3	2.35-1,450[1]	--	10-46
Region 4	2.08-1,230[1]	5,740-10,700	--
Region 6	.20-1,670[1]	--	--
Region 7	5.58-340[1]	6,070-9,560	--
Region 8	.20-1,990[1]	4,300-10,200	--
Region 9	4.00-1,180[1]	6,550-10,060	--

[1]For best results, applications should be limited to basins of less than 200 square miles.
[2]NGVD of 1929.

The first multiple-linear regression study of regional flood frequency for Utah was completed in 1971. Since 1971, more than five multiple-linear regression studies have been completed (Kenney *et al.* 2007). The regression equations used in the calibration of the Utah Department of Transportation CN table performed in this study are the most recently provided equations as of 1997. These equations can be seen in Appendix D. Studies for the next generation of improved regression equations for the state of Utah were recently completed by the USGS in October of 2007. These equations were unavailable during the development of this research. The methods set forth in this research for CN calibration using the USGS regression equations are still applicable if using the latest regression equations. This method of CN calibration would be applicable within any state where flood regionalization studies have been completed by using the equations appropriate for the region of interest.

3 Preceding Research

The concept of CN calibration is not new, and has been researched by many individuals and organizations. CN calibration performed using USGS regression equations is an extension of CN calibration research done by Brigham Young University (BYU) faculty and students. The following is a summary of the background research and concepts which have been the foundation and support of the development of CN calibration using USGS regression equations.

3.1 CN Calibration using Measured Data

CN values determined using measured data are much preferred over any other method of CN calibration since the resulting CN more accurate and site-specific. In 1983, students from Utah State University under the direction of Dr. Richard H. Hawkins compiled and published “A Catalog of Intermountain Watershed Curve Numbers” (Curtis *et. al* 1983). The data used for the watersheds located in Utah were taken from a study contracted out by the Bureau of Land Management. Calibration was done using two methods. The first was the Rallison-Cronshey method which is the same as previously outlined in 2.1.3. The second was the Optimized method. This is a least squares determination of S’ which is done iteratively. A more detailed explanation of this methodology is available in the complied catalog. CN calibration results from this catalog for watersheds in the Price, Utah area are shown below in Table 3-1 through Table 3-3.

Table 3-1: CN Values Calibrated by USU for Coal Creek Tributary (Curtis et al., 1983)

Coal Creek Tributary						
Location: lat 39.33.40 long. 110.40.55				Area: 0.41 mi^2		
Storm	**Date**	**Rainfall**		**Runoff**		**Event CN**
1	10/13/1981	0.3	in	0.039	in	94.17
2	10/3/1981	0.2	in	0.004	in	93.27
3	10/16/1981	0.75	in	0.075	in	85.15
4	10/4/1981	0.4	in	0.001	in	84.85
5	10/12/1981	0.65	in	0.039	in	84.62

Minimum	0.2	in	0.001	in	84.62
Average	0.46	in	0.0316	in	88.41
Maximum	0.75		0.075	in	94.17
Stnd. Dev.	0.2329		0.0304		4.8611

Median	85.1475	
Stnd. Error	0.0177	in
R squared	0.6607	

Opt CN	84.913	
Std Error	0.0175	in
R squared	0.6699	

Table 3-2: CN Values Calibrated by USU for Solider Creek Tributary (Curtis et al., 1983)

Solider Creek Tributary						
Location: lat 39.33.44 long. 110.39.20				Area: 1.25 mi^2		
Storm	**Date**	**Rainfall**		**Runoff**		**Event CN**
1	10/13/1981	0.15	in	0.037	in	97.96
2	10/11/1981	0.26	in	0.067	in	96.62
3	10/15/1981	0.4	in	0.076	in	93.74
4	10/3/1981	0.4	in	0.072	in	93.54
5	10/4/1981	0.2	in	0.001	in	92.15
6	10/16/1981	0.65	in	0.12	in	90.05

Minimum	0.15	in	0.001	in	90.05
Average	0.343333	in	0.062167	in	94.01
Maximum	0.65		0.12	in	97.96
Stnd. Dev.	0.1818		0.0401		2.8924

Median	93.6403	
Stnd. Error	0.0483	in
R squared	-0.4498	

Opt CN	91.6177	
Std Error	0.0377	in
R squared	0.1138	

Table 3-3: CN Values Calibrated by USU for Wattis Branch (Curtis et al., 1983)

Wattis Branch						
Location: lat. 39.31.30, long. 110.52.15				Area: 4.9 mi^2		
Storm	**Date**	**Rainfall**		**Runoff**		**Event CN**
1	10/11/1981	0.1	in	0.009	in	97.63
2	10/17/1981	0.17	in	0.026	in	96.88
3	9/5/1981	0.17	in	0.01	in	95.44
4	10/3/1981	0.2	in	0.01	in	94.43
5	10/11/1981	0.5	in	0.032	in	87.95
6	10/16/1981	0.6	in	0.044	in	86.42

Minimum	0.1	in	0.009	in	86.42
Average	0.29	in	0.021833	in	93.12
Maximum	0.6		0.044	in	97.63
Stnd. Dev.	0.2065		0.0145		4.7556

Median	94.9316	
Stnd. Error	0.0965	in
R squared	-43.0247	

Opt CN	87.1788	
Std Error	0.0113	in
R squared	0.3944	

Results for these watersheds and storm events resulted in fairly high Curve Numbers. Given that these storm events produced rainfall less than that of a 2-year return-period event, high CN values would be expected since CN values generally decrease with increasing return-period (Hawkins 2007). The results presented in this section will be compared to results for the same watersheds obtained using the USGS regression equations in the following chapter.

Although using measured data produces more accurate and site-specific results than other calibration methods, this method of CN calibration presents some difficulties. As previously discussed, setting up enough gauges to be able to accurately interpret the rainfall-runoff relationship can be a challenge. As seen in the results above, encountering storm events of a significant size is not easy. Gauging must take place over an extended period of time in order to be able to come across a storm large enough to clearly observe the runoff response to a storm event and to provide reliable results. Aside from these issues, predicting the frequency and magnitude of flooding would not be possible if measured data was only collected over a short period of time. Use of measured data can generate more precise CN calibrations but the collection of quality data is difficult and uneconomical if CN calibrations are needed over large areas.

3.2 CN Calibration using Historical Gauged Data

Although CN calibration using measured data poses many challenges, there are, however good alternatives to direct measurement. The USGS has numerous stream gauges all over the country as well as within the state of Utah. Decades of historical data are available for each stream gauge. The National Climatic Data Center (NCDC) maintained by NOAA likewise has decades of historical records for numerous rain gauges. Many of these historical records are available via the internet while others are available upon request. As discussed in 2.1.3, if the precipitation (P) and the runoff (R) are known, a CN can then be back-calculated and calibrated for watersheds where the rain and stream gauge data are available. If enough historical data were available, CN calibration on a large scale would be possible using these historical records.

Joel Williams (Williams 2005) of Brigham Young University compiled a database of precipitation and stream flow data for various watersheds in the state of Utah in order to determine the feasibility of developing local CN calibrations with available historical USGS and NOAA data. Several factors must be taken into consideration when using historical data such as:

- Close proximity of the stream and rain gauges which is necessary in order to observe a more direct rainfall-runoff relationship
- Only streams with very few diversions can be used for calibration so as to avoid alteration in flow readings
- Only records occurring during the summer and fall months (July-September) can be used so as to avoid the effects of snowmelt runoff
- Selected storm events must be of great enough significance to produce a noticeable rise in the stream volume (i.e. 0.5 inches or greater)
- Only precipitation records that occurred while the stream gauges were in operation can be used and vice versa so a direct rainfall-runoff relationship can be observed.

Williams was able to locate overlapping precipitation and stream gauge records that met this criterion for a total of 40 rain-stream gauge pairs. The actual hydrograph and precipitation data taken from the historical records for one of the gauge pairs is shown in Figure 3-1 below.

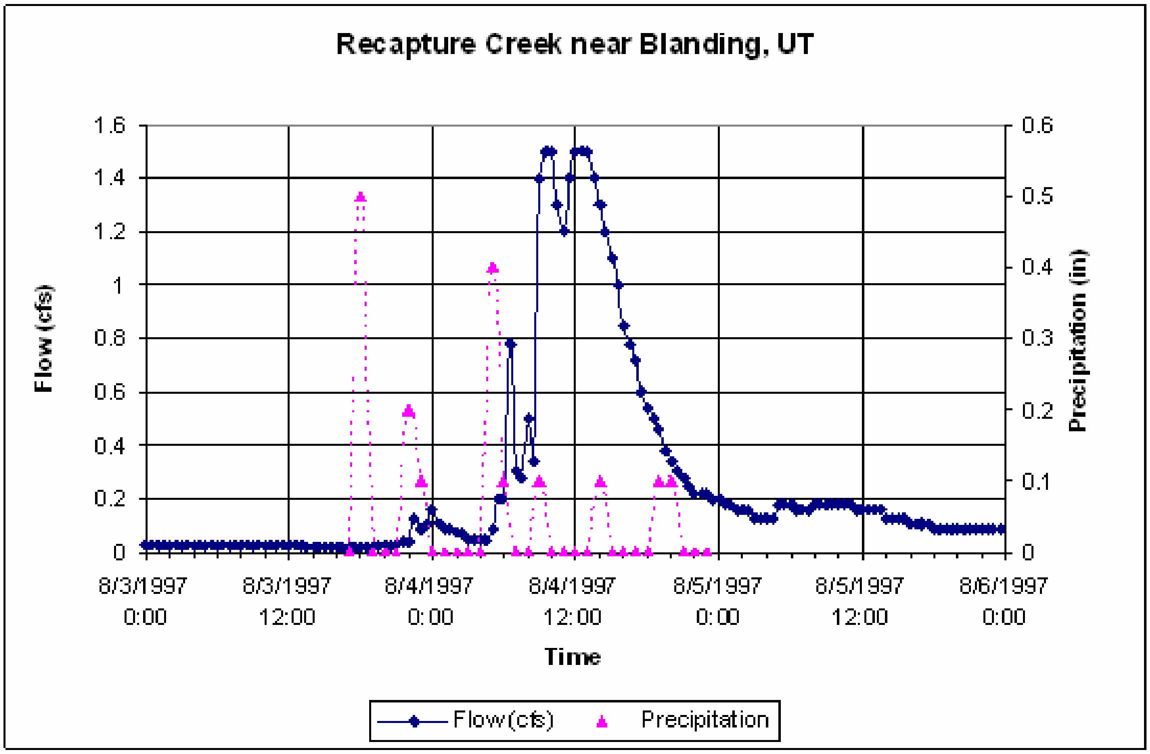


Figure 3-1: Stream and Precipitation Graphs (Williams 2005)

The CN calibration process used by Williams is as follows:

- The watershed was delineated using Watershed Modeling System (WMS) (Nelson 2006), a software program developed by Brigham Young University
- Collected precipitation data was imported into WMS
- A hydrologic runoff model using the SCS unit hydrograph was created from the delineated watershed and precipitation data

- The hydrologic runoff model was then used to determine runoff volume which was calculated from the computed hydrograph
- The input CN was iterated until the predicted runoff volume from the WMS model matched the actual runoff volume from the hydrograph

The results of the CN calibration for these gauge pairs varied with each watershed. When compared to the composite CNs calculated using the CN table currently used by UDOT (see Appendix A), in some cases, the calibrated CN increased while in other cases the CN decreased. While much of the data appeared reasonable there were instances where the calibration produced CN values exceeding 100 or where half the amount of rainfall resulted in twice the runoff from one storm event to another within the same watershed. These discrepancies could be due to gauge malfunction or the fact that the rain and stream gauge were perhaps not close enough to ensure that the same storm event was being measured by both gauges. If a watershed were gauged specifically for the purpose of CN calibration, data overlap, gauge malfunction and proximity issues would not be a concern.

While Williams' research indicates that it is possible to back-calculate a CN from historical data, this method obviously cannot be used in regions where no gauges are present. Historical data can also be unreliable and result in inaccurate calibrations. Although rain and stream gauge data is easily accessible on the internet, painstaking effort was required to first, find concurrent rain and stream gauge data; second, locate gauges in close enough proximity to ensure measurement of the same event; and lastly, find watersheds with available data that meet all other criterion. Use of data measured by others appears convenient but reliable CN calibrations are difficult to obtain using this method.

3.3 Data Catalog and Script for CN Calibration

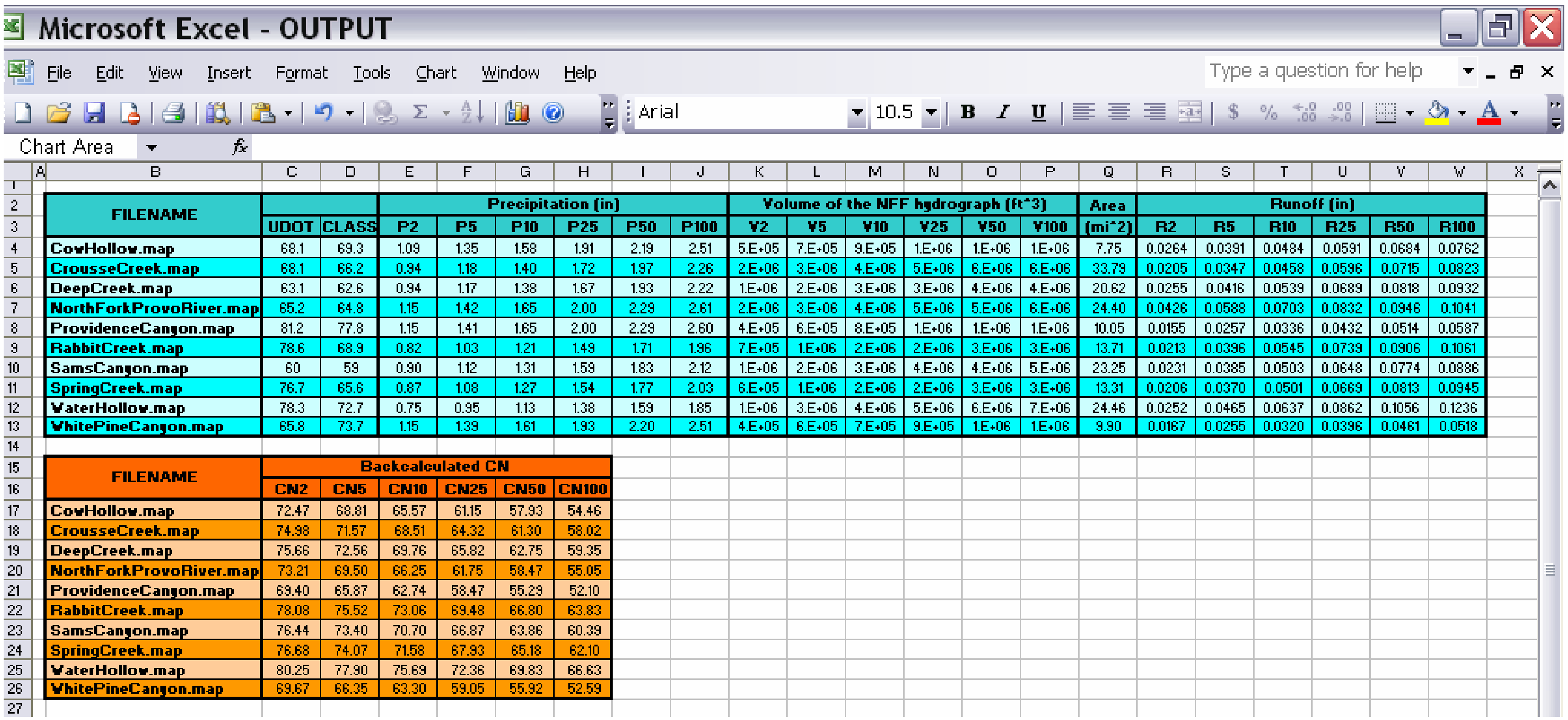
Hydrological study methods have changed dramatically over the last few decades. Much of the processes of today are done digitally. Due to the digitization of hydrological studies, there is an abundance of digital data that are available through government and other agencies via the internet. Digital data that is useful for CN calibration includes:

- Digital Elevation Model (DEM) (http://seamless.usgs.gov/)
- Land Use Coverage (http://www.webgis.com/lulcdata.html)
- Soil Type Coverage (http://www.epa.gov/waterscience/ftp/basins/gis_data/huc/_)
- Precipitation Frequency Data (http://hdsc.nws.noaa.gov/hdsc/pfds/)
- Topographic Maps (http://terraserver.homeadvisor.msn.com/)

Though all of these data are readily available and accessible via the internet, the retrieving and importation of data into software programs can be a time intensive process. If the data is to be used on a regular basis, the compilation of the data into a catalog and the use of a script or simple computer code to locate and process the data can be helpful in streamlining design processes.

Shane Dyer (Dyer 2006) of BYU compiled DEMs, land use and soil type coverages, rainfall grids for precipitation estimation and topographic maps for the whole state of Utah into a catalog for the purpose of calibrating the UDOT CN table using WMS. The NFF program is integrated within WMS. All of the digitized data can be overlaid in WMS and processed for CN calibration using the USGS regression equations. The step-by-step process is available in Appendix B.

Dyer (Dyer 2006) also created a script for the automation of the calibration procedure. The script contains a DO LOOP that opens WMS and inputs the map files created by watershed delineation in WMS. These map files contain the drainage basin area, land use and soil type coverage. With this data, the script then calculates the lag time. The NFF database of USGS regression equations is then used within WMS for peak flow calculations and design hydrograph development for each return-period. Results for each watershed are exported to a text file (Dyer 2006). The script output file can then be imported into an Excel spreadsheet for further calculations. An example spreadsheet is shown in Figure 3-2.



FILENAME	UDOT	CLASS	P2	P5	P10	P25	P50	P100
			Precipitation (in)					
CowHollow.map	68.1	69.3	1.09	1.35	1.58	1.91	2.19	2.51
CrousseCreek.map	68.1	66.2	0.94	1.18	1.40	1.72	1.97	2.26
DeepCreek.map	63.1	62.6	0.94	1.17	1.38	1.67	1.93	2.22
NorthForkProvoRiver.map	65.2	64.8	1.15	1.42	1.65	2.00	2.29	2.61
ProvidenceCanyon.map	81.2	77.8	1.15	1.41	1.65	2.00	2.29	2.60
RabbitCreek.map	78.6	68.9	0.82	1.03	1.21	1.49	1.71	1.96
SamsCanyon.map	60	59	0.90	1.12	1.31	1.59	1.83	2.12
SpringCreek.map	76.7	65.6	0.87	1.08	1.27	1.54	1.77	2.03
WaterHollow.map	78.3	72.7	0.75	0.95	1.13	1.38	1.59	1.85
WhitePineCanyon.map	65.8	73.7	1.15	1.39	1.61	1.93	2.20	2.51

FILENAME	Volume of the NFF hydrograph (ft^3)						Area
	V2	V5	V10	V25	V50	V100	(mi^2)
CowHollow.map	5.E+05	7.E+05	9.E+05	1.E+06	1.E+06	1.E+06	7.75
CrousseCreek.map	2.E+06	3.E+06	4.E+06	5.E+06	6.E+06	6.E+06	33.79
DeepCreek.map	1.E+06	2.E+06	3.E+06	3.E+06	4.E+06	4.E+06	20.62
NorthForkProvoRiver.map	2.E+06	3.E+06	4.E+06	5.E+06	5.E+06	6.E+06	24.40
ProvidenceCanyon.map	4.E+05	6.E+05	8.E+05	1.E+06	1.E+06	1.E+06	10.05
RabbitCreek.map	7.E+05	1.E+06	2.E+06	2.E+06	3.E+06	3.E+06	13.71
SamsCanyon.map	1.E+06	2.E+06	3.E+06	4.E+06	4.E+06	5.E+06	23.25
SpringCreek.map	6.E+05	1.E+06	2.E+06	2.E+06	3.E+06	3.E+06	13.31
WaterHollow.map	1.E+06	3.E+06	4.E+06	5.E+06	6.E+06	7.E+06	24.46
WhitePineCanyon.map	4.E+05	6.E+05	7.E+05	9.E+05	1.E+06	1.E+06	9.90

FILENAME	Runoff (in)					
	R2	R5	R10	R25	R50	R100
CowHollow.map	0.0264	0.0391	0.0484	0.0591	0.0684	0.0762
CrousseCreek.map	0.0205	0.0347	0.0458	0.0596	0.0715	0.0823
DeepCreek.map	0.0255	0.0416	0.0539	0.0689	0.0818	0.0932
NorthForkProvoRiver.map	0.0426	0.0588	0.0703	0.0832	0.0946	0.1041
ProvidenceCanyon.map	0.0155	0.0257	0.0336	0.0432	0.0514	0.0587
RabbitCreek.map	0.0213	0.0396	0.0545	0.0739	0.0906	0.1061
SamsCanyon.map	0.0231	0.0385	0.0503	0.0648	0.0774	0.0886
SpringCreek.map	0.0206	0.0370	0.0501	0.0669	0.0813	0.0945
WaterHollow.map	0.0252	0.0465	0.0637	0.0862	0.1056	0.1236
WhitePineCanyon.map	0.0167	0.0255	0.0320	0.0396	0.0461	0.0518

FILENAME	Backcalculated CN					
	CN2	CN5	CN10	CN25	CN50	CN100
CowHollow.map	72.47	68.81	65.57	61.15	57.93	54.46
CrousseCreek.map	74.98	71.57	68.51	64.32	61.30	58.02
DeepCreek.map	75.66	72.56	69.76	65.82	62.75	59.35
NorthForkProvoRiver.map	73.21	69.50	66.25	61.75	58.47	55.05
ProvidenceCanyon.map	69.40	65.87	62.74	58.47	55.29	52.10
RabbitCreek.map	78.08	75.52	73.06	69.48	66.80	63.83
SamsCanyon.map	76.44	73.40	70.70	66.87	63.86	60.39
SpringCreek.map	76.68	74.07	71.58	67.93	65.18	62.10
WaterHollow.map	80.25	77.90	75.69	72.36	69.83	66.63
WhitePineCanyon.map	69.67	66.35	63.30	59.05	55.92	52.59

Figure 3-2: Script Output in Excel Spreadsheet

An explanation of the data contained in the spreadsheet is as follows:

- **FILENAME**: Filename of the WMS map file used in the script.
- **UDOT**: Composite CN for the watershed calculated using the CN table currently used by UDOT for comparison purposes.
- **CLASS**: Composite CN for the watershed calculated using the CN table researched by BYU students for comparison purposes.
- **P2 through P100**: Precipitation for each return-period from NOAA Atlas 14 rainfall grids.
- **V2 through V100**: Runoff volume for each return-period calculated for each return-period using the NFF design hydrograph.
- **Area**: Watershed area calculated in WMS.
- **R2 through R100**: Average runoff depth calculated by dividing the runoff volume (V2 through V100) by the watershed area.
- **CN 2 through CN 100**: Back-calculated CN for each return-period using P and R values for the respective return-period in Equation 2.5:

$$CN = \frac{200}{P + 2R - \sqrt{5PR + 4R^2} + 2}$$

The compilation of this database and development of the script would allow CN calibration using the USGS regression equations for particular watersheds to be performed quickly. However, much research as to the validity of this method was yet to be explored.

4 Methods and Procedures

Reliable measured data is difficult to obtain. Consistent CN calibrations are also consequently hard to come by. The USGS regression equations were developed for this reason: to provide good estimations of peak flow and runoff where gauged data is unavailable. Use of the USGS regression equations is pervasive throughout the engineering industry. The regression equations are also rooted in historical gauged data. All of these factors support the potential use of the regression equations in CN calibration.

UDOT currently uses the CN method in many of their design procedures. Along with other organizations within the industry, UDOT is unlikely to develop new methods of runoff estimation due to the familiarity and the widespread use of the CN method. UDOT does however desire to improve the accuracy and consistency of the method's use within the state of Utah by calibrating their current CN table for local conditions. Given that the direct measurement and collection of data for CN calibration can be such a demanding process, a more feasible method of calibration is necessary for the extensive (i.e. the whole state of Utah) CN calibrations needed by UDOT. UDOT also frequently uses USGS flood estimation for many of their projects. Considering the scale at which calibration is needed, and UDOT's previous experience with and use of the USGS regression equations in design, the use of USGS regression equations for CN calibration would be an appropriate and practical method of obtaining data for use in CN calibration. Thus, the UDOT CN table will be used as an illustration of this process.

In order to justify the use of the regression equations in CN calibration, regression equation calibration was applied to regions where gauged data has been obtained previously in the studies by Utah State University students and Joel Williams of BYU as discussed in 3.1 and 3.2 respectively.

4.1 Measured Data CN Calibration Comparison

The watersheds located in Utah that were researched by Utah State University (Curtis *et. al* 1983) were used for comparison in order to validate the use of regression equations in CN calibration. These three watersheds are all located near Price, Utah. In order to compare these methods, a DEM, land use shapefile and soil type shapefile for the region surrounding the basin outlet coordinates given in Table 3-1 through Table 3-3 were imported into WMS using the catalog compiled by Dyer (Dyer 2006). The watersheds were then delineated and the resulting map files were saved and process using the script also developed by Dyer (Dyer 2006). The complete process utilized in WMS is outlined in Appendix B. With the availability of the catalog and script, only the first few steps of Appendix B are done manually. The remaining steps have been automated by the script. The script output is then imported into WMS so that the CN values for the respective return-periods could be calculated. The output spreadsheet for three watersheds (Coal Creek Tributary, Solider Creek Tributary and Wattis Branch) previously studied by Utah State University is shown below in Table 4-1.

Table 4-1: Script Output and Calibrated CNs for Utah State University Watersheds

FILENAME			Precipitation (in)						Volume of the NFF hydrograph (ft^3)						Area	Runoff (in)					
	UDOT	CLASS	P2	P5	P10	P25	P50	P100	V2	V5	V10	V25	V50	V100	(mi^2)	R2	R5	R10	R25	R50	R100
Coal Creek	76.8	76.8	0.74	0.92	1.08	1.30	1.50	1.75	2.E+03	1.E+04	2.E+04	1.E+05	2.E+05	3.E+05	0.40	0.0027	0.0119	0.0263	0.1193	0.1873	0.2817
Solider Creek	77	77	0.77	0.95	1.12	1.35	1.55	1.81	1.E+04	5.E+04	1.E+05	4.E+05	6.E+05	9.E+05	1.24	0.0048	0.0184	0.0372	0.1406	0.2087	0.2980
Wattis Branch	78.6	78.6	0.82	1.01	1.18	1.42	1.64	1.91	9.E+04	3.E+05	5.E+05	1.E+06	2.E+06	2.E+06	5.04	0.0079	0.0229	0.0404	0.1081	0.1495	0.2002

FILENAME	Backcalculated CN					
	CN2	CN5	CN10	CN25	CN50	CN100
Coal Creek	75.56	73.75	72.75	76.12	76.07	75.54
Solider Creek	75.79	74.26	73.28	76.41	76.01	75.14
Wattis Branch	75.44	73.67	72.29	73.07	71.65	69.74

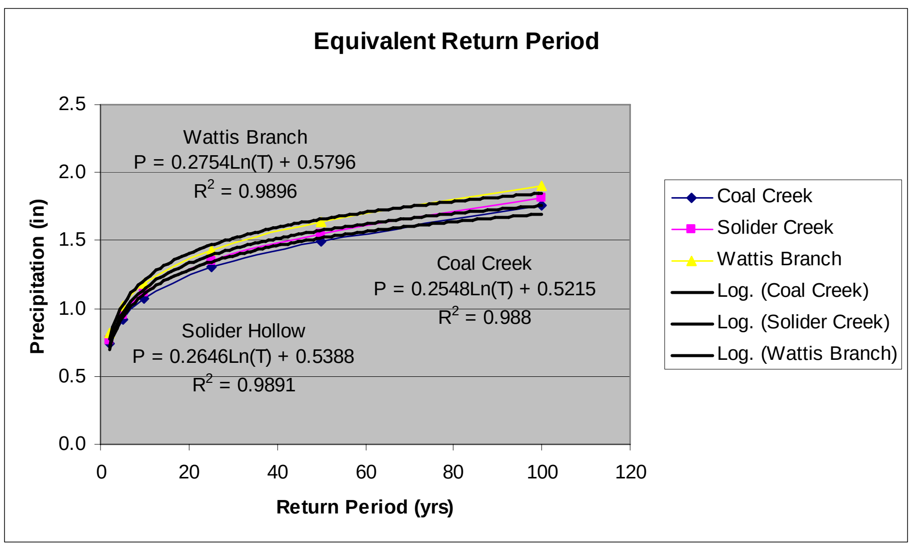


Figure 4-1: Equivalent Return-Period Equation Derivation for USU Watersheds

In order to compare the resulting CN calibrations, the precipitation data used by USU was translated into an equivalent return-period. This was accomplished by first graphing the return-period against the precipitation values from the output file (P2 through P100) as seen in Figure 4-1. A trend line and an associated equation were developed for each watershed. The equations relate return-period (T) to precipitation depth (P). The equations can also be seen in Figure 4-1. The precipitation data from Table 3-1 through Table 3-3 were inserted into the respective equations to solve for a return-period (T). For example, the trend line equation for Coal Creek Tributary is:

$$P = 0.2548 Ln(T) + 0.5215$$

Storm 1 for Coal Creek Tributary in Table 3-1, the rainfall was 0.3 inches. Inserting 0.3 into the above equation results in a return-period (T) of 0.43 years. This process was preformed for each storm evaluated by USU. The CN values from the output spreadsheet were then plotted against return-period. The CNs calibrated by USU for each storm were plotted on the same graph with the associated equivalent return-period previously calculated. The average of all the storms was also plotted with a line connecting to the data produced using the script and USGS regression equations to better illustrate their relationship. The results are shown below.

Table 4-2: Coal Creek Data Comparison

USU Coal Creek Tributary Data			
Storm	CN	P (in)	T (yrs)
1	94.17	0.3	0.42
2	93.27	0.2	0.28
3	85.15	0.75	2.45
4	84.85	0.4	0.62
5	84.62	0.65	1.66
Avg	88.41	0.46	0.79
BYU 2-year	75.56	0.741	2

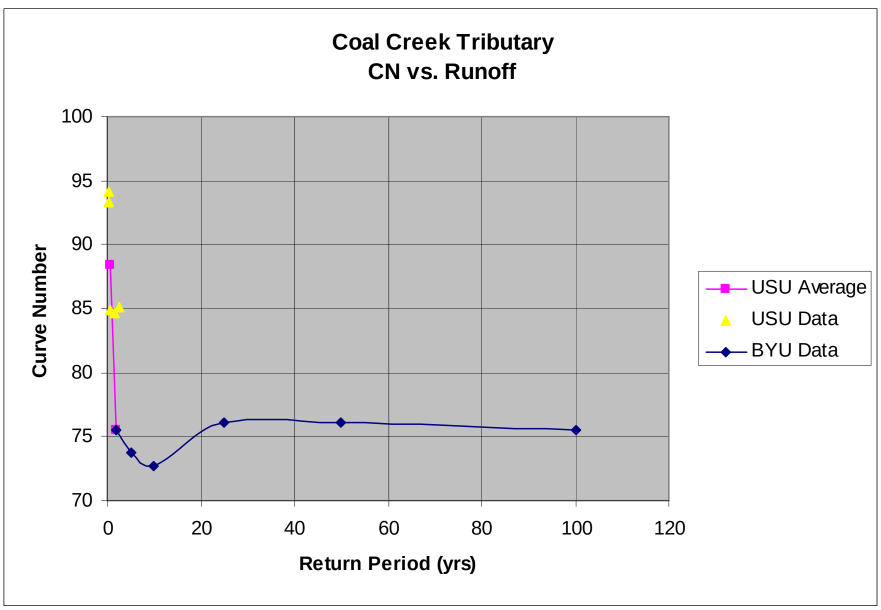


Figure 4-2: Coal Creek Tributary Data Comparison Graph

Table 4-3: Solider Creek Comparison Data

USU Solider Creek Tributary Data			
Storm	CN	P (in)	T (yrs)
1	97.96	0.15	0.23
2	96.62	0.26	0.35
3	93.74	0.40	0.59
4	93.54	0.40	0.59
5	92.15	0.20	0.28
6	90.05	0.65	1.52
Avg	94.01	0.06	0.17
BYU 2-year	75.79	0.77	2

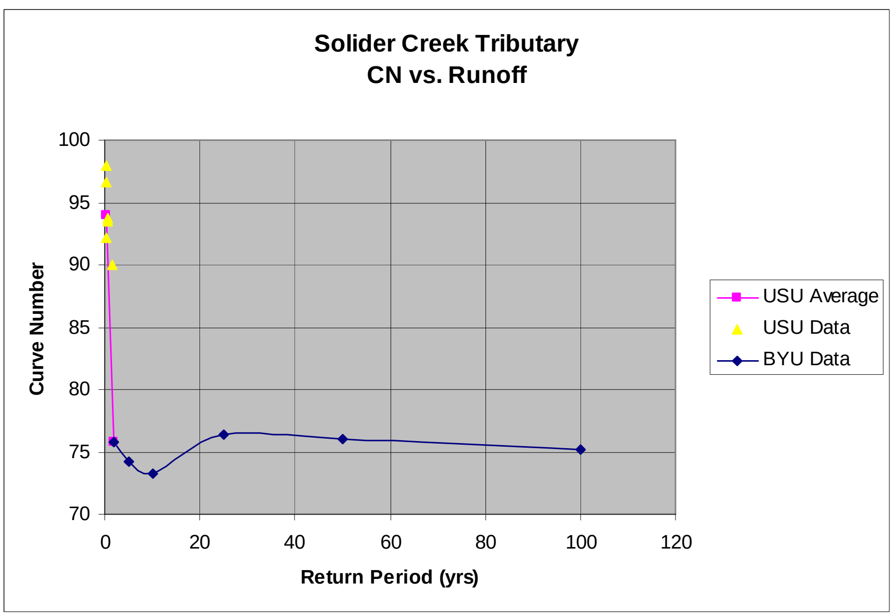


Figure 4-3: Solider Creek Tributary Data Comparison Graph

Table 4-4: Wattis Branch Comparison Data

USU Wattis Branch Data			
Storm	CN	P (in)	T (yrs)
1	97.63	0.10	0.18
2	96.88	0.17	0.23
3	95.44	0.17	0.23
4	94.43	0.20	0.25
5	87.95	0.50	0.75
6	86.42	0.60	1.08
Avg	93.12	0.29	0.35
BYU 2-year	75.44	0.01	2

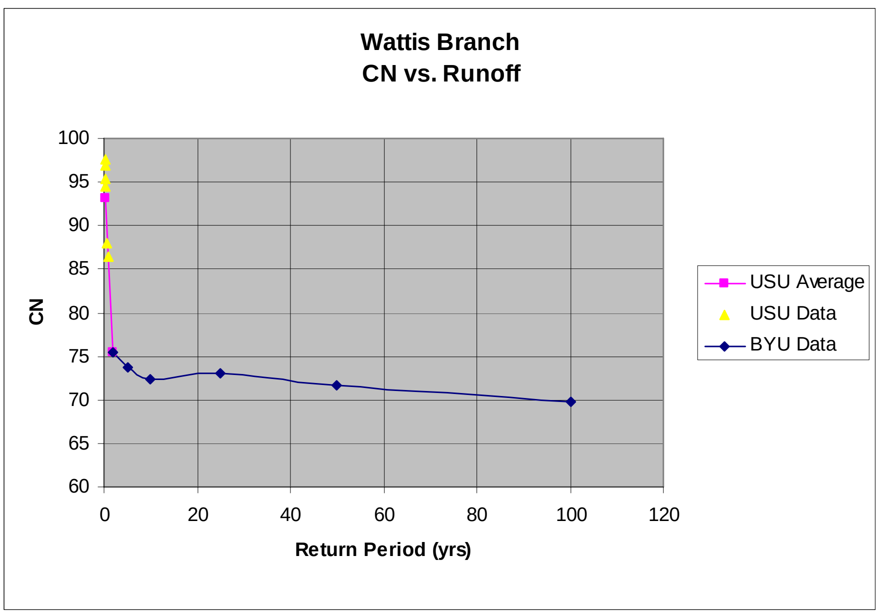


Figure 4-4: Wattis Branch Data Comparison Graph

As discussed in 3.1, the Curve Number generally increases with decreasing return-period (Hawkins 2007). Although there appears to be a hump in the data near the 25-year return-period, the data does generally follow this trend. Using gauged data for storms of a larger size would be a better comparison for this research since the USGS regression equations are only available for as small as a 2-year return-period. Encountering a storm of larger size is not probable so there is limited data for larger storm events. The USU data however falls where it would be expected on the graph given the small amount of precipitation of the each storm. Although it is not an exact fit, the results of this comparison are encouraging since the general shape of the graph is close to what was expected.

4.2 Historical Gauged Data CN Calibration Comparison

In an attempt to further confirm the validity of the use of regression equations in CN calibration, CNs calibrated using historical gauged data from Joel William's (Williams 2005) research were compared to results using the regression equations. Three of Williams' forty gauge pairs were selected for comparison. These gauge pairs were considered a good choice for the comparison since the historical precipitation and stream gauge data were well correlated and resulted in reasonable calibrations. Some CN calibrations in Williams' research produced very unreasonable results due to the distance between the rain and stream gauge. To avoid this problem, the selected gauges were located within or very close to the watershed. The gauge pairs include Beaver River near Beaver, Utah, Centerville Creek near Centerville, Utah, and Coal Creek near Cedar City, Utah. The Coal Creek used for this comparison is at a different location than the Coal

Creek Tributary used in the USU research. The location of these watersheds and their gauges can be seen in Figure 4-5 below.

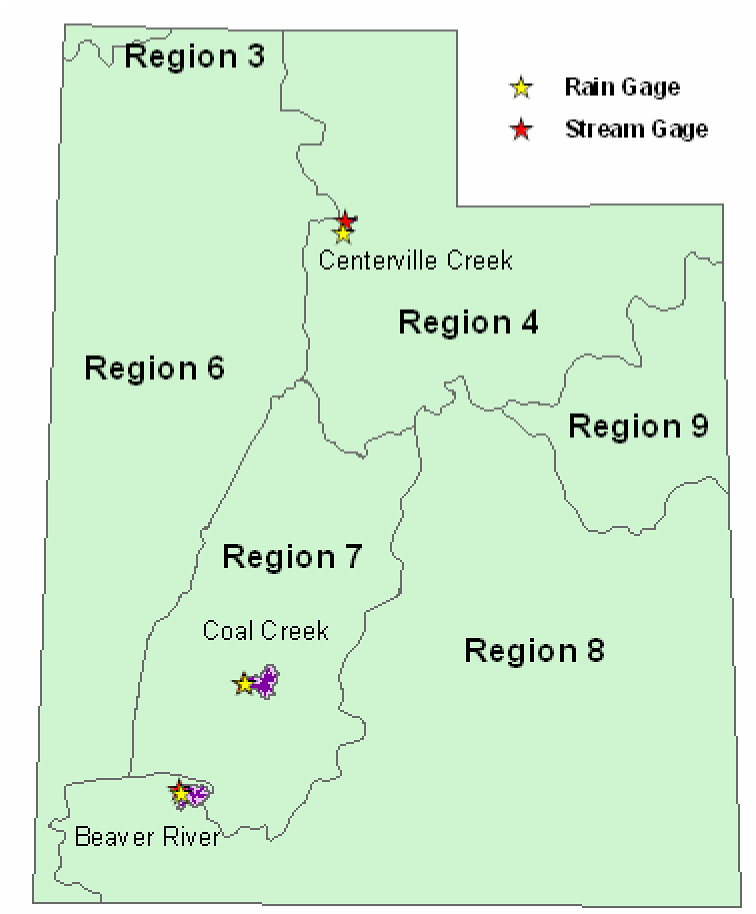


Figure 4-5: Location of Watersheds with Historical Data

The Beaver River watershed gauge coordinates and storm data are shown below in Table 4-5. The hydrograph in Figure 4-6 was developed as a part of Williams' research. This hydrograph depicts the actual storm event rather than an average hydrograph which is an estimation used for design purposes only. It can be seen in Figure 4-7 that the rain gauge (indicated by the yellow star) used for this watershed is located within the basin, which greatly improves the chances that the rain and stream gauge have recorded data for the same storm.

Table 4-5: Beaver River CN Calibration Data Summary

Precipitation Gage:	Beaver 4 E, Beaver County, UT					
Location (lat/long: d,m,s):	38	17	0	112	34	0
Stream Gage:	Beaver River near Beaver, UT					
Location (lat/long: d,m,s):	38	16	50	112	34	3
Date of Storm:	8/7/1987					
Basin Area (mi^2):	91.72					
Total Precipitation (in):	1.4					
Base Flow (cfs):	46					
Peak Flow (cfs):	77					
Runoff Volume (ft^3):	2772000					
UDOT CN:	61.4					
Gaged CN:	64					

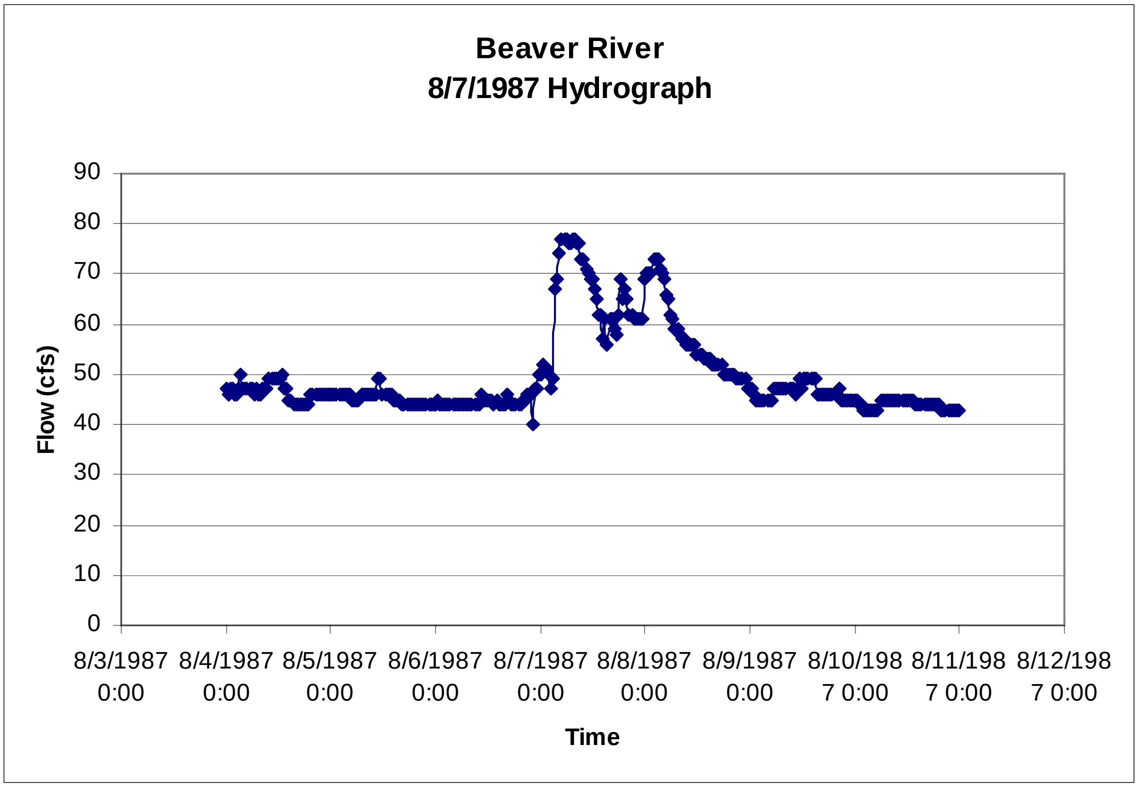


Figure 4-6: Beaver River 8/7/1987 Hydrograph (Williams 2005)

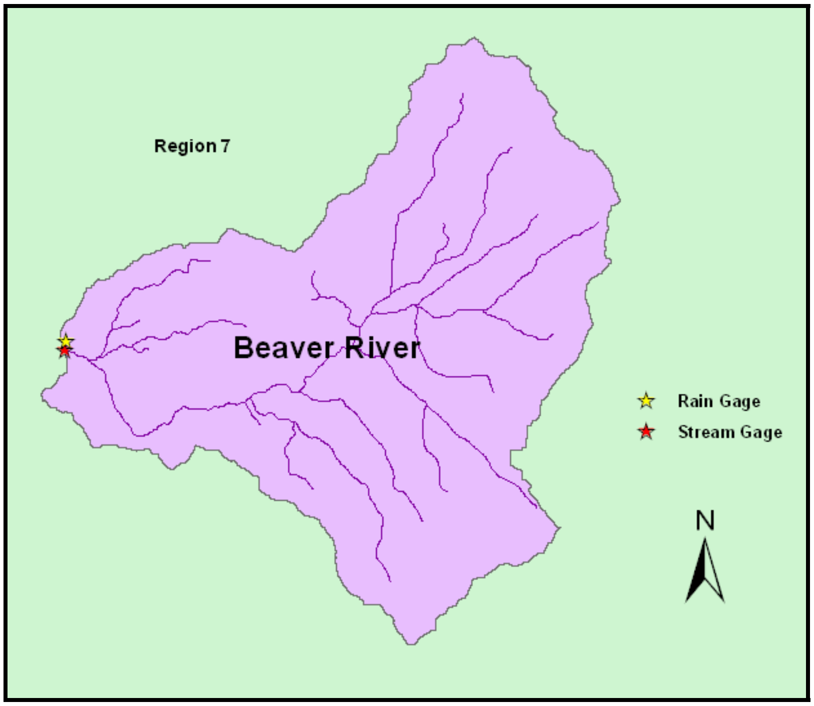


Figure 4-7: Beaver River Gauge Locations

As can be seen in Figure 4-5 and Figure 4-7, Beaver River is located in the NFF Region 7. The watershed was delineated using WMS, and the map files were run through the script using the Region 7 USGS regression equations. The output for Beaver River can be seen in Table 4-6 along with the results for Centerville and Coal Creek. As discussed previously, the precipitation comes from the NOAA Atlas 14 rainfall grid, and the runoff volume is determined using the design hydrograph. The runoff is calculated by dividing the runoff volume by the basin area. With this data, Curve Numbers indexed by return-period could then be back-calculated as seen in Table 4-6.

Table 4-6: Script Output for Historical Gauged Data

FILENAME			Precipitation (in)						Volume of the NFF hydrograph (ft^3)						Area	Runoff (in)					
	UDOT	CLASS	P2	P5	P10	P25	P50	P100	V2	V5	V10	V25	V50	V100	(mi^2)	R2	R5	R10	R25	R50	R100
BeaverRiver.map	62.2	61.4	1.44	1.76	2.04	2.44	2.77	3.16	6.E+06	1.E+07	1.E+07	1.E+07	2.E+07	2.E+07	91.72	0.0289	0.0450	0.0579	0.0656	0.0785	0.0919
CentervilleCreek.map	65.9	69.3	1.33	1.59	1.83	2.19	2.50	2.86	8.E+04	1.E+05	2.E+05	3.E+05	3.E+05	4.E+05	3.17	0.0105	0.0197	0.0271	0.0368	0.0451	0.0527
CoalCreek.map	67.9	61.9	1.48	1.83	2.13	2.56	2.92	3.32	6.E+06	1.E+07	2.E+07	3.E+07	3.E+07	4.E+07	77.77	0.0343	0.0685	0.0965	0.1429	0.1848	0.2283

FILENAME	Backcalculated CN					
	CN2	CN5	CN10	CN25	CN50	CN100
BeaverRiver.map	65.90	62.16	59.23	54.51	51.60	48.47
CentervilleCreek.map	64.87	61.90	59.08	55.16	52.20	48.91
CoalCreek.map	65.80	63.22	60.80	57.73	55.46	53.00

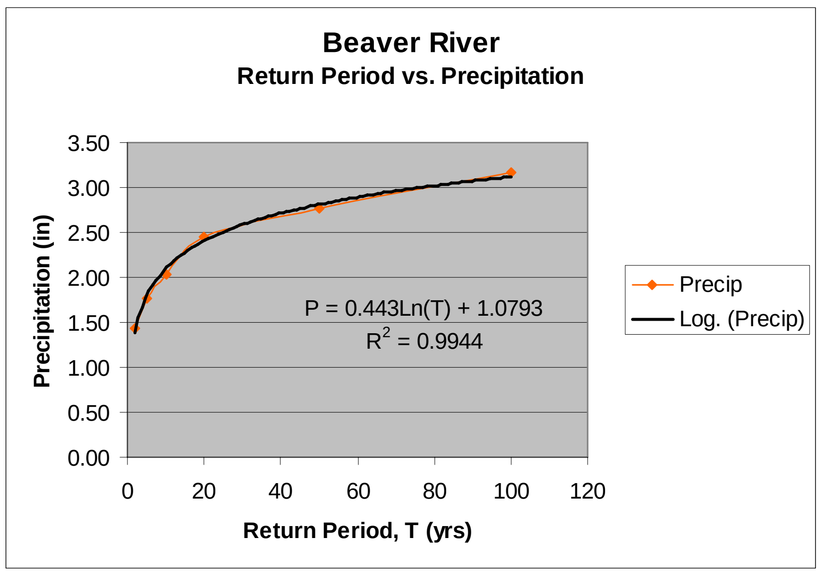


Figure 4-8: Beaver River Equivalent Return-Period Equation Derivation

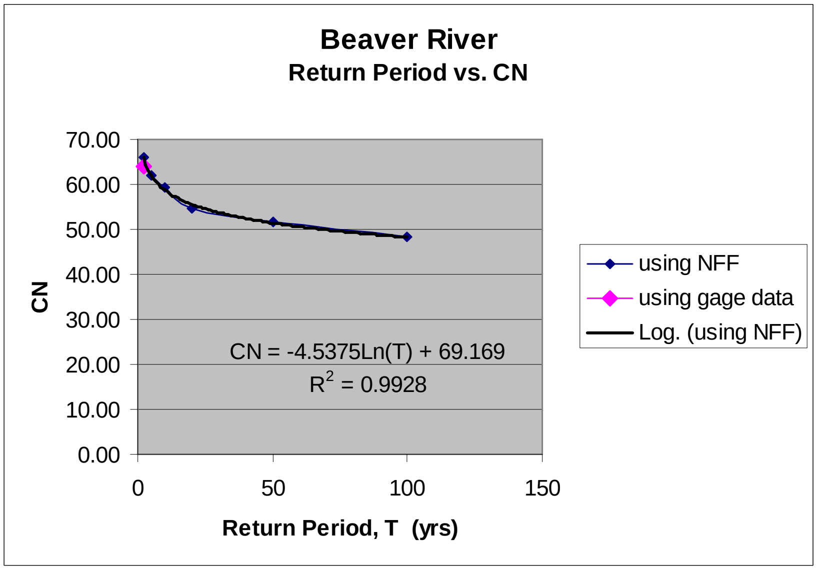


Figure 4-9: Equivalent CN Equation Derivation

In order to determine how the USGS regression equation calibration method compares to the gauged data calibration, the same procedure was used as was used for the USU data. The NOAA precipitation was plotted against the return-period as seen in Figure 4-8. A trend line was then plotted. With the associated equation, the equivalent return-period can be calculated for the gauged precipitation. As noted in Table 4-5, the total precipitation for the storm occurring on 8/7/1987 was 1.4 inches. Setting P equal to 1.4 inches in the following equation results in an equivalent return-period of T = 2.1 years.

$$P = 0.443Ln(T) + 1.0793 \tag{4-1}$$

The calibrated CNs were then plotted against the return-period and again, a trend line was drawn resulting in Equation 3-2 below.

$$CN = -4.5375Ln(T) + 69.169 \tag{4-2}$$

The equivalent return-period for the historical data of 2.1 years was then inserted into Equation 4-2 in order to estimate the CN that would be calibrated for the measured precipitation data if calibrated using the regional regression equations. The resulting calibrated CN was 65.9. This estimation is an increase of 2.9% from the CN of 64, calibrated using the historical gauged data.

The same procedure was similarly used for the Centerville Creek and Coal Creek watersheds. The maps, tables, graphs and equations for these watersheds can be viewed in Appendix E. For Centerville Creek the gauged CN calibration was 69 where as the regression equation calibration was 67, a 2.9% decrease. For Coal Creek, the gauged CN was 69.1 and the regression equation CN was 66.9, a 3.3% decrease. With such consistent results, it appeared that CN calibration using the regional regression equations was a viable option where gauged data are unavailable.

4.3 CN Calibration using USGS Regression Equations

After determining that using the USGS regression equations was an appropriate means of calibration, roughly ten watersheds from each NFF region were selected for research in order to determine if any regional trends exist and what recommendations could be made to UDOT for the improvement of their CN table. Only watersheds with few upstream diversions and a basin area greater than 10 square miles were chosen for the study. These selection guidelines were used in order to stay within the limitations of the regression equations (Table 2-3) and the CN method. A map of the selected watersheds can be seen in Figure 4-10 below.

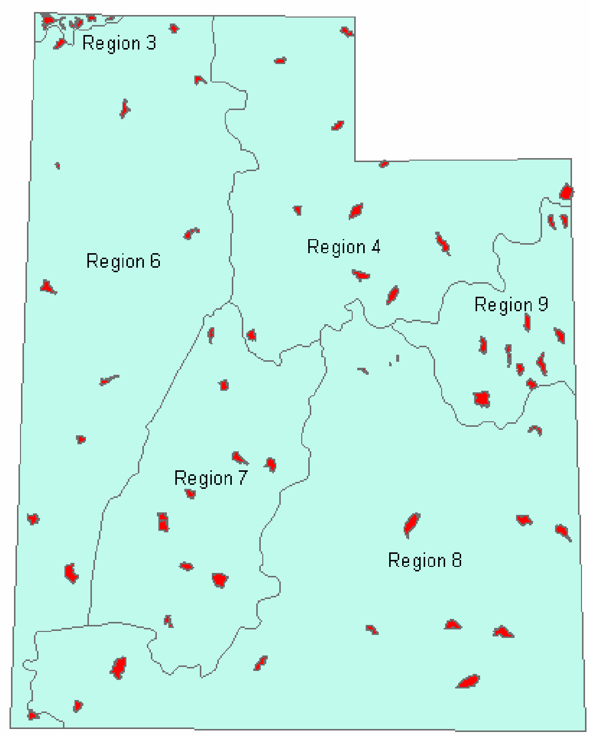


Figure 4-10: Watersheds used in Regional Trend Study

The catalog developed by Dyer (Dyer 2006) was again used for data acquisition and watershed selection. The selected watersheds were processed with the script. The output and back-calculated Curve Numbers for each watershed and return-period have been indexed by region and can be seen in the following section. Region 3 is so small that watersheds wholly contained in the region that were of reasonable size so as to produce reliable results were difficult to find. Therefore, Region 3 was neglected in the study.

5 Results

The results for the regional trend study for the state of Utah are shown by NFF region in Table 5-1 through Table 5-5. Definitions for the majority of the output were outlined previously in 3.3. In this section, a new portion of the output tables entitled “Scalars” has appeared. UDOT has requested suggestions on how to modify their CN table to account for the local conditions in various locations in Utah. The values in the scalar table were calculated by taking the back-calculated or calibrated CN of each return-period and dividing by the composite CN that was calculated using the unmodified UDOT CN table for the respective watershed. Near the bottom of the scalar table, there are two rows entitled “WTD AVG” and “AVG”. “WTD AVG” indicates a weighted average of all the watershed scalars for a particular return-period. The weighted average was weighted by watershed area. The row entitled “AVG” is a straight average of the calculated scalars for each return-period. Theoretically, if enough watersheds were calibrated using this method in each NFF region, composite CNs calculated using the unmodified UDOT CN table could be multiplied by the weighted average scalar of the NFF region to adjust for the local conditions as well as the return-period for which the project is being designed.

Table 5-1: Region 4 Calibrated Curve Numbers and Scalars

FILENAME			Precipitation (in)						Volume of the NFF hydrograph (ft^3)						Area	Runoff (in)					
	UDOT	CLASS	P2	P5	P10	P25	P50	P100	V2	V5	V10	V25	V50	V100	(mi^2)	R2	R5	R10	R25	R50	R100
CowHollow.map	68.1	69.3	1.09	1.35	1.58	1.91	2.19	2.51	5.E+05	7.E+05	9.E+05	1.E+06	1.E+06	1.E+06	7.75	0.0264	0.0391	0.0484	0.0591	0.0684	0.0762
CrousseCreek.map	68.1	66.2	0.94	1.18	1.40	1.72	1.97	2.26	2.E+06	3.E+06	4.E+06	5.E+06	6.E+06	6.E+06	33.79	0.0205	0.0347	0.0458	0.0596	0.0715	0.0823
DeepCreek.map	63.1	62.6	0.94	1.17	1.38	1.67	1.93	2.22	1.E+06	2.E+06	3.E+06	3.E+06	4.E+06	4.E+06	20.62	0.0255	0.0416	0.0539	0.0689	0.0818	0.0932
NorthForkProvoRiver.map	65.2	64.8	1.15	1.42	1.65	2.00	2.29	2.61	2.E+06	3.E+06	4.E+06	5.E+06	5.E+06	6.E+06	24.40	0.0426	0.0588	0.0703	0.0832	0.0946	0.1041
ProvidenceCanyon.map	81.2	77.8	1.15	1.41	1.65	2.00	2.29	2.60	4.E+05	6.E+05	8.E+05	1.E+06	1.E+06	1.E+06	10.05	0.0155	0.0257	0.0336	0.0432	0.0514	0.0587
RabbitCreek.map	78.6	68.9	0.82	1.03	1.21	1.49	1.71	1.96	7.E+05	1.E+06	2.E+06	2.E+06	3.E+06	3.E+06	13.71	0.0213	0.0396	0.0545	0.0739	0.0906	0.1061
SamsCanyon.map	60	59	0.90	1.12	1.31	1.59	1.83	2.12	1.E+06	2.E+06	3.E+06	4.E+06	4.E+06	5.E+06	23.25	0.0231	0.0385	0.0503	0.0648	0.0774	0.0886
SpringCreek.map	76.7	65.6	0.87	1.08	1.27	1.54	1.77	2.03	6.E+05	1.E+06	2.E+06	2.E+06	3.E+06	3.E+06	13.31	0.0206	0.0370	0.0501	0.0669	0.0813	0.0945
WaterHollow.map	78.3	72.7	0.75	0.95	1.13	1.38	1.59	1.85	1.E+06	3.E+06	4.E+06	5.E+06	6.E+06	7.E+06	24.46	0.0252	0.0465	0.0637	0.0862	0.1056	0.1236
WhitePineCanyon.map	65.8	73.7	1.15	1.39	1.61	1.93	2.20	2.51	4.E+05	6.E+05	7.E+05	9.E+05	1.E+06	1.E+06	9.90	0.0167	0.0255	0.0320	0.0396	0.0461	0.0518

FILENAME	Backcalculated CN					
	CN2	CN5	CN10	CN25	CN50	CN100
CowHollow.map	72.47	68.81	65.57	61.15	57.93	54.46
CrousseCreek.map	74.98	71.57	68.51	64.32	61.30	58.02
DeepCreek.map	75.66	72.56	69.76	65.82	62.75	59.35
NorthForkProvoRiver.map	73.21	69.50	66.25	61.75	58.47	55.05
ProvidenceCanyon.map	69.40	65.87	62.74	58.47	55.29	52.10
RabbitCreek.map	78.08	75.52	73.06	69.48	66.80	63.83
SamsCanyon.map	76.44	73.40	70.70	66.87	63.86	60.39
SpringCreek.map	76.68	74.07	71.58	67.93	65.18	62.10
WaterHollow.map	80.25	77.90	75.69	72.36	69.83	66.63
WhitePineCanyon.map	69.67	66.35	63.30	59.05	55.92	52.59

	SCALAR					
	S2	S5	S10	S25	S50	S100
	1.06	1.01	0.96	0.90	0.85	0.80
	1.10	1.05	1.01	0.94	0.90	0.85
	1.20	1.15	1.11	1.04	0.99	0.94
	1.12	1.07	1.02	0.95	0.90	0.84
	0.85	0.81	0.77	0.72	0.68	0.64
	0.99	0.96	0.93	0.88	0.85	0.81
	1.27	1.22	1.18	1.11	1.06	1.01
	1.00	0.97	0.93	0.89	0.85	0.81
	1.02	0.99	0.97	0.92	0.89	0.85
	1.06	1.01	0.96	0.90	0.85	0.80
WTD AVG:	**1.09**	**1.05**	**1.01**	**0.95**	**0.91**	**0.86**
AVG:	**1.07**	**1.02**	**0.98**	**0.93**	**0.88**	**0.84**

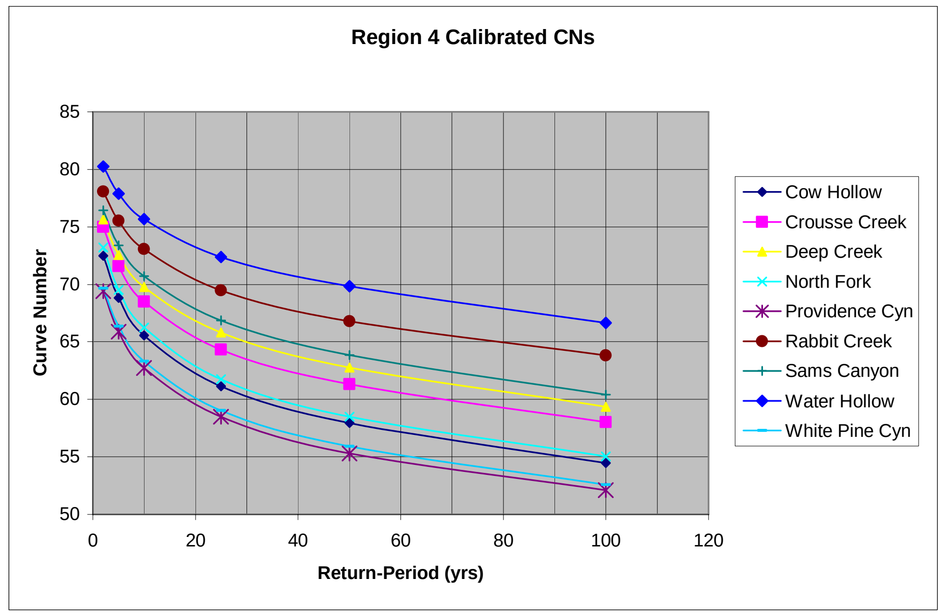


Figure 5-1: Region 4 Calibrated Curve Number Graph

Table 5-2: Region 6 Calibrated Curve Numbers and Scalars

FILENAME			Precipitation (in)						Volume of the NFF hydrograph (ft^3)						Area	Runoff (in)					
	UDOT	CLASS	P2	P5	P10	P25	P50	P100	V2	V5	V10	V25	V50	V100	(mi^2)	R2	R5	R10	R25	R50	R100
BlackhamCanyon.map	61.4	60.2	0.88	1.11	1.30	1.58	1.81	2.08	-----	3.E+05	5.E+05	1.E+06	2.E+06	4.E+06	10.67	-----	0.0108	0.0219	0.0460	0.0799	0.1518
BoxCanyon.map	71	69.6	0.84	1.05	1.23	1.49	1.70	1.94	-----	7.E+05	1.E+06	3.E+06	6.E+06	1.E+07	12.30	-----	0.0250	0.0517	0.1115	0.1941	0.3654
BoxElderWash.map	75.6	73.9	1.06	1.28	1.48	1.76	2.00	2.28	-----	6.E+05	1.E+06	2.E+06	4.E+06	7.E+06	14.72	-----	0.0172	0.0326	0.0682	0.1192	0.2166
CaveCreek.map	88.8	81	0.67	0.85	1.00	1.23	1.41	1.63	-----	6.E+04	2.E+05	4.E+05	8.E+05	2.E+06	2.85	-----	0.0095	0.0291	0.0672	0.1136	0.2657
FourmileDraw.map	74.3	73.4	0.98	1.23	1.45	1.77	2.02	2.32	-----	2.E+06	4.E+06	8.E+06	1.E+07	2.E+07	35.05	-----	0.0253	0.0438	0.0949	0.1687	0.2778
JacksonWash.map	73	73	1.15	1.44	1.69	2.05	2.34	2.66	-----	4.E+05	7.E+05	1.E+06	3.E+06	4.E+06	17.44	-----	0.0104	0.0178	0.0358	0.0628	0.1099
KimbellCreek.map	69.4	64.8	0.95	1.19	1.41	1.71	1.96	2.25	-----	5.E+05	9.E+05	2.E+06	3.E+06	6.E+06	13.59	-----	0.0149	0.0293	0.0622	0.1086	0.2005
NewfoundlandBasin.map	68.8	64.5	0.64	0.81	0.95	1.17	1.35	1.56	-----	1.E+06	3.E+06	7.E+06	1.E+07	2.E+07	15.22	-----	0.0279	0.0744	0.1873	0.3276	0.6384
NorthCanyon.map	65.7	64.4	0.93	1.15	1.34	1.62	1.86	2.13	-----	5.E+05	1.E+06	3.E+06	6.E+06	1.E+07	10.45	-----	0.0217	0.0587	0.1436	0.2492	0.5040
RoseRanchCreek.map	79.9	69	0.83	1.04	1.22	1.48	1.70	1.96	-----	5.E+05	1.E+06	3.E+06	5.E+06	1.E+07	11.29	-----	0.0173	0.0473	0.1174	0.2042	0.4112

FILENAME	Backcalculated CN					
	CN2	CN5	CN10	CN25	CN50	CN100
BlackhamCanyon.map	-----	69.34	67.46	65.28	64.40	64.71
BoxCanyon.map	-----	73.09	72.45	72.12	72.90	75.43
BoxElderWash.map	-----	67.10	65.63	64.25	64.11	64.94
CaveCreek.map	-----	75.04	74.81	73.93	73.63	77.03
FourmileDraw.map	-----	69.28	67.39	66.22	66.39	66.78
JacksonWash.map	-----	62.76	59.96	57.01	55.58	54.74
KimbellCreek.map	-----	68.38	66.53	64.59	64.02	64.60
NewfoundlandBasin.map	-----	79.25	80.37	82.21	84.03	88.31
NorthCanyon.map	-----	70.58	71.00	71.64	72.59	76.66
RoseRanchCreek.map	-----	72.20	72.28	72.57	73.21	76.56

	SCALAR					
	S2	S5	S10	S25	S50	S100
	-----	1.13	1.10	1.06	1.05	1.05
	-----	1.03	1.02	1.02	1.03	1.06
	-----	0.89	0.87	0.85	0.85	0.86
	-----	0.85	0.84	0.83	0.83	0.87
	-----	0.93	0.91	0.89	0.89	0.90
	-----	0.86	0.82	0.78	0.76	0.75
	-----	0.99	0.96	0.93	0.92	0.93
	-----	1.15	1.17	1.19	1.22	1.28
	-----	1.07	1.08	1.09	1.10	1.17
	-----	0.90	0.90	0.91	0.92	0.96
WTD AVG:	-----	**0.98**	**0.96**	**0.95**	**0.95**	**0.97**
AVG:	-----	**0.98**	**0.97**	**0.96**	**0.96**	**0.98**

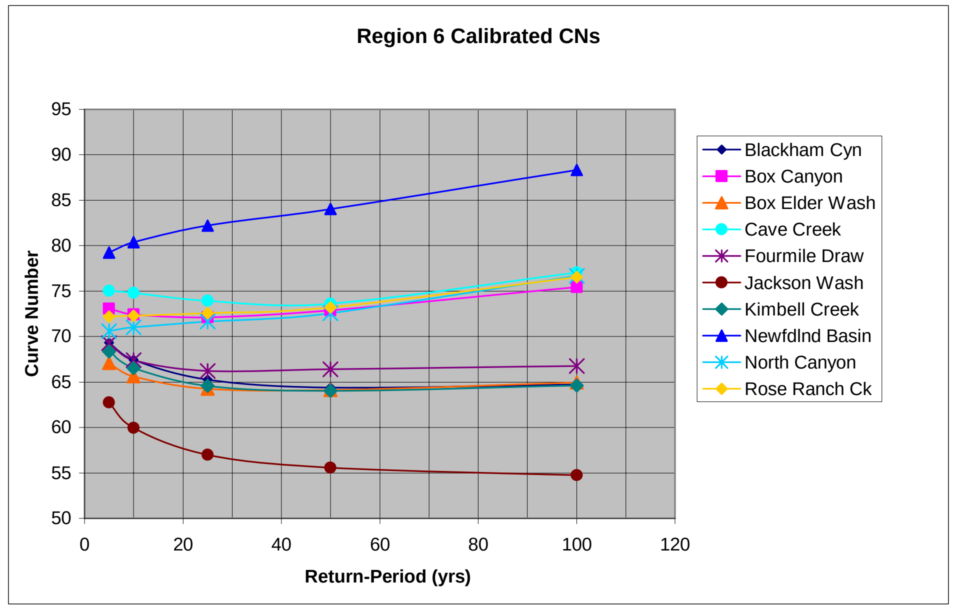


Figure 5-2: Region 6 Calibrated Curve Number Graph

Table 5-3: Region 7 Calibrated Curve Numbers and Scalars

FILENAME			Precipitation (in)					
	UDOT	CLASS	P2	P5	P10	P25	P50	P100
CunninghamWash.map	75.1	71.1	1.01	1.26	1.47	1.78	2.03	2.33
DogValleyCreek.map	69.5	66.5	0.95	1.19	1.38	1.67	1.90	2.17
FoolCreek.map	60	59	0.99	1.23	1.43	1.70	1.93	2.21
HorseCreek.map	62.3	62.6	1.42	1.76	2.05	2.47	2.83	3.23
JerichoWash.map	79.5	78.6	0.83	1.03	1.20	1.45	1.65	1.89
LeesSpringWash.map	65.8	64.3	1.00	1.24	1.45	1.75	2.00	2.29
LostCreek.map	75.2	74.4	1.04	1.29	1.51	1.83	2.09	2.42
RidgeCreek.map	78.6	78.4	1.06	1.30	1.52	1.82	2.07	2.38
SoliderCreek.map	74.4	71.7	0.84	1.04	1.22	1.47	1.69	1.95
WaterCanyon.map	75.9	71.0	0.97	1.22	1.42	1.72	1.96	2.26

FILENAME	Volume of the NFF hydrograph (ft^3)						Area	Runoff (in)					
	V2	V5	V10	V25	V50	V100	(mi^2)	R2	R5	R10	R25	R50	R100
CunninghamWash.map	3.E+05	8.E+05	1.E+06	3.E+06	3.E+06	4.E+06	19.57	0.007	0.017	0.027	0.055	0.071	0.090
DogValleyCreek.map	2.E+05	5.E+05	8.E+05	2.E+06	2.E+06	3.E+06	11.95	0.007	0.018	0.029	0.063	0.084	0.108
FoolCreek.map	2.E+05	5.E+05	8.E+05	2.E+06	2.E+06	3.E+06	14.97	0.006	0.015	0.023	0.053	0.069	0.088
HorseCreek.map	6.E+05	1.E+06	2.E+06	2.E+06	3.E+06	4.E+06	10.88	0.025	0.049	0.071	0.092	0.122	0.158
JerichoWash.map	2.E+05	6.E+05	1.E+06	3.E+06	4.E+06	6.E+06	10.17	0.008	0.024	0.043	0.140	0.187	0.243
LeesSpringWash.map	3.E+05	8.E+05	1.E+06	3.E+06	3.E+06	4.E+06	15.56	0.009	0.021	0.034	0.070	0.092	0.117
LostCreek.map	9.E+05	2.E+06	3.E+06	4.E+06	5.E+06	6.E+06	34.90	0.011	0.022	0.032	0.050	0.062	0.077
RidgeCreek.map	7.E+05	1.E+06	2.E+06	4.E+06	5.E+06	6.E+06	19.69	0.014	0.031	0.047	0.084	0.108	0.136
SoliderCreek.map	3.E+05	8.E+05	1.E+06	3.E+06	4.E+06	5.E+06	20.01	0.007	0.018	0.029	0.070	0.091	0.114
WaterCanyon.map	2.E+05	5.E+05	8.E+05	2.E+06	2.E+06	3.E+06	13.77	0.006	0.015	0.025	0.056	0.073	0.094

FILENAME	Backcalculated CN					
	CN2	CN5	CN10	CN25	CN50	CN100
CunninghamWash.map	70.61	67.40	64.95	62.90	60.46	57.63
DogValleyCreek.map	71.86	69.01	66.84	65.40	63.26	60.89
FoolCreek.map	70.54	67.61	65.35	63.93	61.68	59.14
HorseCreek.map	65.66	62.53	60.08	55.92	53.56	51.10
JerichoWash.map	74.98	73.42	72.14	74.61	73.36	71.81
LeesSpringWash.map	71.40	68.54	66.33	64.62	62.34	59.79
LostCreek.map	71.06	67.70	65.01	61.64	58.83	55.61
RidgeCreek.map	71.21	68.71	66.59	64.60	62.32	59.73
SoliderCreek.map	74.64	72.13	70.06	69.43	67.16	64.51
WaterCanyon.map	71.04	67.90	65.53	63.86	61.57	58.87

	SCALAR					
	S2	S5	S10	S25	S50	S100
	0.94	0.90	0.86	0.84	0.81	0.77
	1.03	0.99	0.96	0.94	0.91	0.88
	1.18	1.13	1.09	1.07	1.03	0.99
	1.05	1.00	0.96	0.90	0.86	0.82
	0.94	0.92	0.91	0.94	0.92	0.90
	1.09	1.04	1.01	0.98	0.95	0.91
	0.94	0.90	0.86	0.82	0.78	0.74
	0.91	0.87	0.85	0.82	0.79	0.76
	1.00	0.97	0.94	0.93	0.90	0.87
	0.94	0.89	0.86	0.84	0.81	0.78
WTD AVG:	0.99	0.95	0.92	0.89	0.86	0.82
AVG:	1.00	0.96	0.93	0.91	0.88	0.84

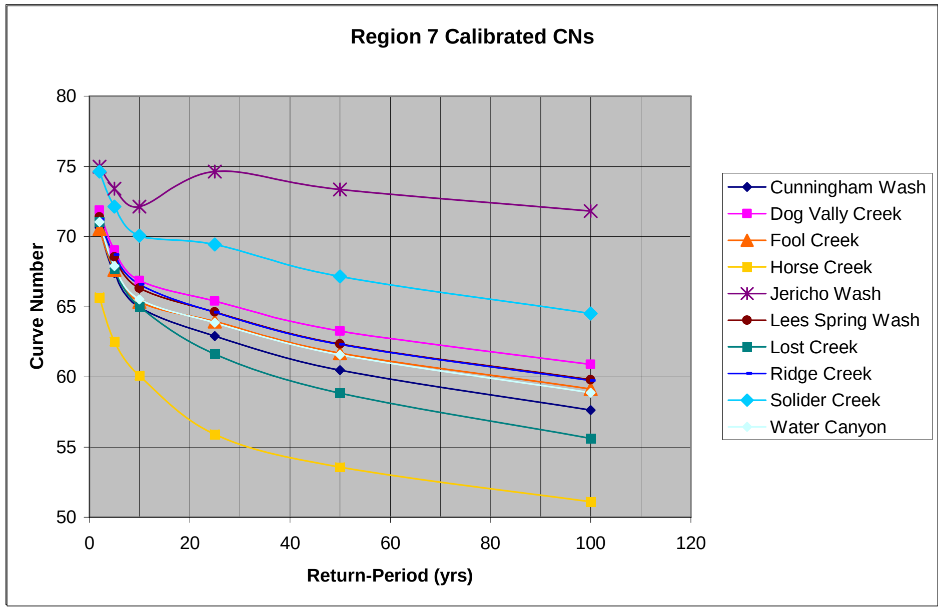


Figure 5-3: Region 7 Calibrated Curve Numbers Graph

Table 5-4: Region 8 Calibrated Curve Numbers and Scalars (using Region 8 equation)

FILENAME			Precipitation (in)						Volume of the NFF hydrograph (ft^3)						Area	Runoff (in)					
	UDOT	CLASS	P2	P5	P10	P25	P50	P100	V2	V5	V10	V25	V50	V100	(mi^2)	R2	R5	R10	R25	R50	R100
ClayCanyon.map	74.7	65.3	0.70	0.89	1.06	1.32	1.53	1.81	3.E+06	9.E+06	1.E+07	2.E+07	3.E+07	4.E+07	11.78	0.1237	0.3135	0.4935	0.7994	1.0884	1.4161
CottonwoodWash.map	67.2	64.8	0.87	1.11	1.31	1.59	1.83	2.08	4.E+06	1.E+07	2.E+07	3.E+07	4.E+07	6.E+07	13.20	0.1345	0.3787	0.6259	1.0511	1.4598	1.9375
DryCanyon.map	78.8	73.1	0.75	0.95	1.12	1.38	1.60	1.87	4.E+06	9.E+06	1.E+07	2.E+07	3.E+07	4.E+07	10.57	0.1461	0.3647	0.5702	0.9193	1.2484	1.6201
HammondCanyon.map	75.8	74.5	0.98	1.23	1.46	1.78	2.06	2.37	5.E+06	1.E+07	2.E+07	2.E+07	3.E+07	4.E+07	27.87	0.0755	0.1672	0.2473	0.3809	0.5040	0.6373
Hanksville.map	66.9	64.6	0.67	0.86	1.02	1.27	1.48	1.76	1.E+07	3.E+07	4.E+07	6.E+07	8.E+07	1.E+08	36.32	0.1315	0.3118	0.4759	0.7500	1.0046	1.2860
HunterCanyon.map	87.8	81.8	0.75	0.95	1.13	1.40	1.64	1.92	5.E+06	1.E+07	2.E+07	3.E+07	4.E+07	6.E+07	22.23	0.1031	0.2508	0.3875	0.6174	0.8324	1.0726
LaSal.map	51.5	52.3	1.03	1.28	1.50	1.84	2.12	2.45	3.E+06	6.E+06	9.E+06	1.E+07	2.E+07	2.E+07	23.29	0.0546	0.1150	0.1661	0.2518	0.3301	0.4136
LongCanyon.map	67.2	63.6	0.80	1.01	1.20	1.48	1.72	2.01	5.E+06	1.E+07	2.E+07	3.E+07	4.E+07	5.E+07	21.17	0.0962	0.2289	0.3499	0.5532	0.7426	0.9528
RoundValleyDraw.map	82.3	79.1	0.89	1.13	1.33	1.62	1.87	2.17	4.E+06	9.E+06	1.E+07	2.E+07	3.E+07	4.E+07	16.20	0.1021	0.2378	0.3600	0.5657	0.7570	0.9681
SlickhornCanyon.map	72.6	71.1	0.81	1.03	1.23	1.51	1.75	2.04	9.E+06	2.E+07	3.E+07	5.E+07	7.E+07	8.E+07	38.07	0.1059	0.2423	0.3638	0.5662	0.7532	0.9575

FILENAME	Backcalculated CN					
	CN2	CN5	CN10	CN25	CN50	CN100
ClayCanyon.map	89.18	91.70	92.87	94.37	95.54	96.32
CottonwoodWash.map	85.90	89.64	91.75	94.42	96.57	98.77
DryCanyon.map	89.07	92.04	93.43	95.21	96.62	97.71
HammondCanyon.map	79.84	80.03	79.34	78.41	77.66	76.45
Hanksville.map	90.16	92.30	93.14	94.28	95.13	95.36
HunterCanyon.map	86.85	88.79	89.47	90.17	90.67	90.73
LaSal.map	76.96	76.26	74.91	73.02	71.52	69.43
LongCanyon.map	85.42	86.91	87.27	87.68	87.97	87.70
RoundValleyDraw.map	83.61	85.08	85.43	85.80	86.10	85.80
SlickhornCanyon.map	85.67	87.02	87.24	87.51	87.69	87.40

	SCALAR					
	S2	S5	S10	S25	S50	S100
	1.19	1.23	1.24	1.26	1.28	1.29
	1.28	1.33	1.37	1.41	1.44	1.47
	1.13	1.17	1.19	1.21	1.23	1.24
	1.05	1.06	1.05	1.03	1.02	1.01
	1.35	1.38	1.39	1.41	1.42	1.43
	0.99	1.01	1.02	1.03	1.03	1.03
	1.49	1.48	1.45	1.42	1.39	1.35
	1.27	1.29	1.30	1.30	1.31	1.31
	1.02	1.03	1.04	1.04	1.05	1.04
	1.18	1.20	1.20	1.21	1.21	1.20
WTD AVG:	1.21	1.23	1.23	1.23	1.24	1.23
AVG:	1.20	1.22	1.22	1.23	1.24	1.24

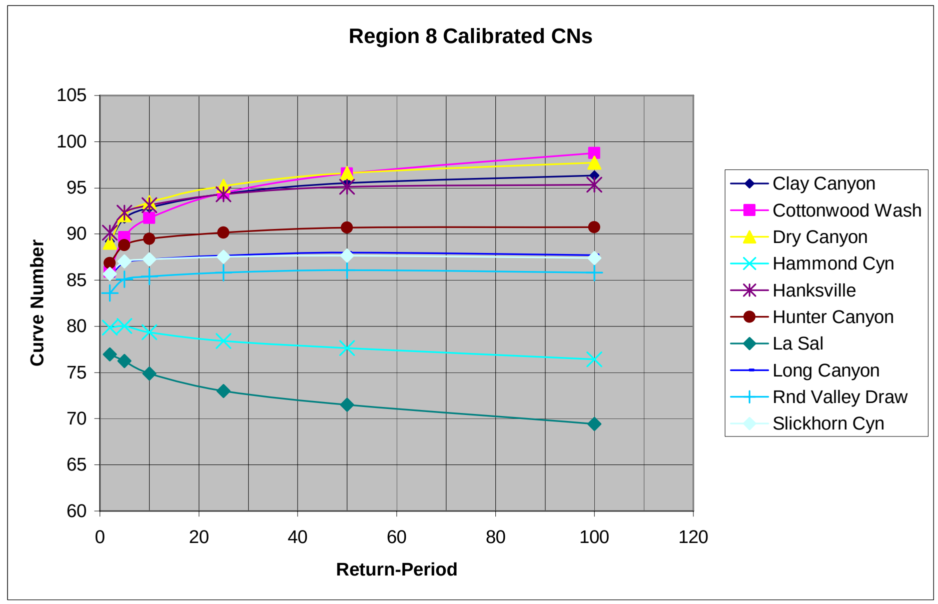


Figure 5-4: Region 8 Calibrated Curve Number Graph

Table 5-5: Region 9 Calibrated Curve Numbers and Scalars

FILENAME			Precipitation (in)						Volume of the NFF hydrograph (ft^3)						Area	Runoff (in)					
	UDOT	CLASS	P2	P5	P10	P25	P50	P100	V2	V5	V10	V25	V50	V100	(mi^2)	R2	R5	R10	R25	R50	R100
AgencyWash.map	64	61.8	0.77	0.97	1.14	1.40	1.62	1.89	8.E+05	2.E+06	3.E+06	6.E+06	1.E+07	1.E+07	13.14	0.028	0.063	0.103	0.191	0.317	0.369
FlorenceCreek.map	64.5	64	0.86	1.09	1.28	1.57	1.82	2.14	2.E+06	5.E+06	7.E+06	1.E+07	1.E+07	2.E+07	40.50	0.025	0.048	0.069	0.107	0.151	0.175
LongWash.map	62.3	60.9	0.75	0.95	1.12	1.38	1.59	1.84	1.E+06	2.E+06	4.E+06	7.E+06	1.E+07	1.E+07	19.98	0.022	0.048	0.079	0.145	0.242	0.281
MainBottomCanyon.map	62.8	61.2	0.81	1.01	1.20	1.47	1.70	1.98	6.E+05	1.E+06	2.E+06	4.E+06	6.E+06	7.E+06	13.28	0.021	0.045	0.071	0.121	0.185	0.215
MeadowCreek.map	77.5	73.3	0.91	1.13	1.33	1.63	1.88	2.18	7.E+05	1.E+06	2.E+06	3.E+06	5.E+06	6.E+06	15.26	0.020	0.042	0.062	0.098	0.139	0.161
RedWash.map	77.1	74	0.77	0.98	1.17	1.44	1.65	1.91	3.E+05	8.E+05	1.E+06	3.E+06	5.E+06	6.E+06	11.09	0.013	0.031	0.055	0.112	0.205	0.238
SandCreek.map	66	64	0.69	0.88	1.04	1.28	1.47	1.72	7.E+05	2.E+06	3.E+06	6.E+06	1.E+07	1.E+07	16.25	0.017	0.042	0.074	0.156	0.295	0.343
SeepCanyon.map	75.6	73.8	0.84	1.06	1.24	1.52	1.75	2.04	2.E+06	4.E+06	6.E+06	9.E+06	1.E+07	2.E+07	22.05	0.035	0.073	0.110	0.180	0.268	0.310
StonebridgeDraw.map	63.3	61.6	0.78	1.00	1.18	1.46	1.68	1.93	4.E+05	9.E+05	1.E+06	3.E+06	5.E+06	6.E+06	10.92	0.014	0.034	0.058	0.112	0.194	0.226
TabyagaCanyon.map	65.8	62.8	0.74	0.93	1.10	1.35	1.57	1.83	7.E+05	2.E+06	3.E+06	5.E+06	9.E+06	1.E+07	18.24	0.017	0.039	0.066	0.127	0.222	0.257

FILENAME	Backcalculated CN					
	CN2	CN5	CN10	CN25	CN50	CN100
AgencyWash.map	80.30	79.19	78.35	77.96	79.02	76.31
FlorenceCreek.map	77.50	75.11	73.00	70.34	68.64	65.01
LongWash.map	79.79	78.21	77.04	76.19	76.84	74.07
MainBottomCanyon.map	78.28	76.45	74.85	73.07	72.47	69.27
MeadowCreek.map	75.68	73.46	71.38	68.71	67.09	63.71
RedWash.map	77.69	75.53	74.04	73.08	74.07	71.33
SandCreek.map	80.67	79.24	78.48	78.66	80.77	78.29
SeepCanyon.map	79.31	77.96	76.67	75.28	75.01	72.10
StonebridgeDraw.map	77.71	75.56	73.98	72.73	73.23	70.47
TabyagaCanyon.map	79.38	77.58	76.38	75.57	76.28	73.28

	SCALAR					
	S2	S5	S10	S25	S50	S100
	1.25	1.24	1.22	1.22	1.23	1.19
	1.20	1.16	1.13	1.09	1.06	1.01
	1.28	1.26	1.24	1.22	1.23	1.19
	1.25	1.22	1.19	1.16	1.15	1.10
	0.98	0.95	0.92	0.89	0.87	0.82
	1.01	0.98	0.96	0.95	0.96	0.93
	1.22	1.20	1.19	1.19	1.22	1.19
	1.05	1.03	1.01	1.00	0.99	0.95
	1.23	1.19	1.17	1.15	1.16	1.11
	1.21	1.18	1.16	1.15	1.16	1.11
WTD AVG:	1.17	1.14	1.12	1.10	1.10	1.05
AVG:	1.17	1.14	1.12	1.10	1.10	1.06

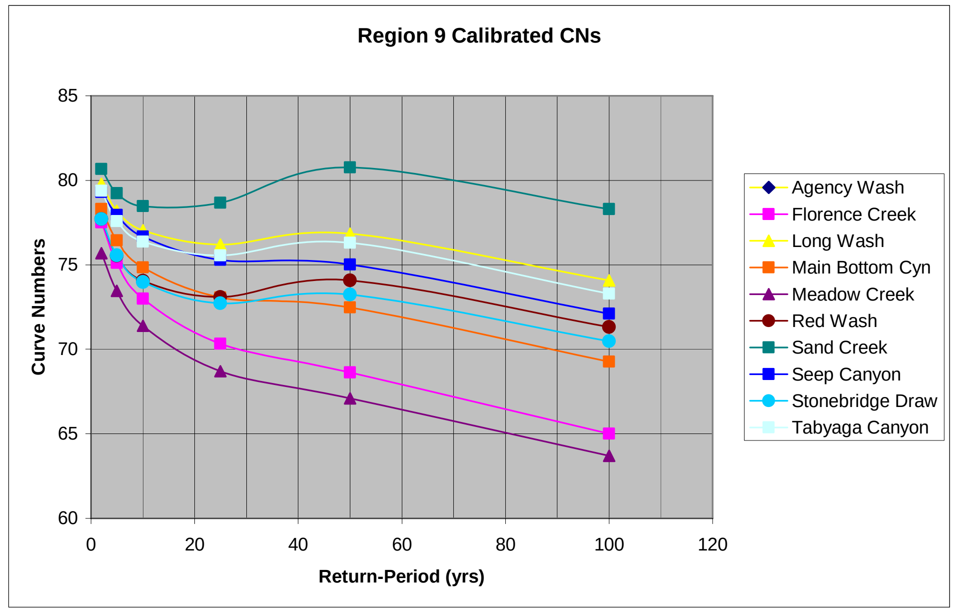


Figure 5-5: Region 9 Calibrated Curve Number Graph

6 Discussion

6.1 Regional Trends

There are several interesting trends in the calibration results. One of the more obvious trends typical of the majority of the regions is the decrease in the back-calculated Curve Number with increasing return-period. As discussed previously, this trend is to be expected since the greater the return-period, the more precipitation (P) and runoff (R). If both P and R increase with increasing return-period, this would cause the denominator of the CN back-calculation equation as seen below to increase, thus decreasing the CN with increasing return-period.

$$CN = \frac{200}{P + 2R - \sqrt{5PR + 4R^2} + 2} \tag{6-1}$$

The results of Region 4 (see Figure 5-1) are precisely what would be anticipated in all regions. This trend was present in all regions but was not, however, completely consistent in all cases. The calibrated CNs for the majority of the study watersheds in Region 8 and some in Region 6 actually increased with increasing return-period as seen in Figure 5-4 and Figure 5-2 which suggests that the regression equations are predicting a disproportionate amount of runoff for the amount of rainfall present, and that there is a progressively greater proportion of runoff to rainfall with increasing return-period. It should be noted in Figure 2-5 that both Region 6 and Region 8 are the largest of the Utah NFF Regions and perhaps the least populated. Region 6 extends from the southern all the way to the northern border of Utah. The climate and geology varies greatly from north to the south in Utah. The consistency of the regression equations over such large areas may be questionable when considering the results of this study.

Upon further investigation, it was noticed that abnormalities in the data appeared to be location based. Watersheds resulting in increasing Curve Numbers with increasing return-period were often clustered together. The Region 6 graph was color-coded in Figure 6-1 to illustrate this concept. The yellow data are those that were considered abnormal. The pink data are those that conformed to the expected trend

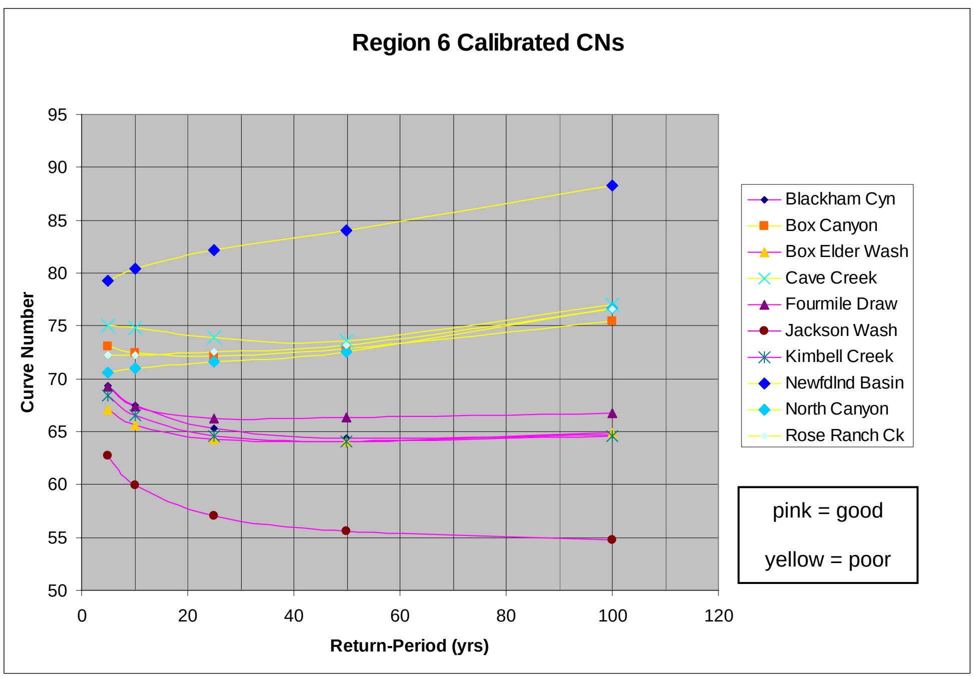


Figure 6-1: Region 6 Data Analysis

All the watersheds processed for Region 6 are shown in Figure 6-1. The watersheds were also color-coded and correlate with the graph in Figure 6-2. Again, the yellow watersheds indicate those with atypical data, and the pink indicate those with normal results. As seen in Figure 6-2, watersheds with results that were as expected seem to be clustered mostly at the bottom end of the region. A single watershed near the top of the region also resulted in fair output data.

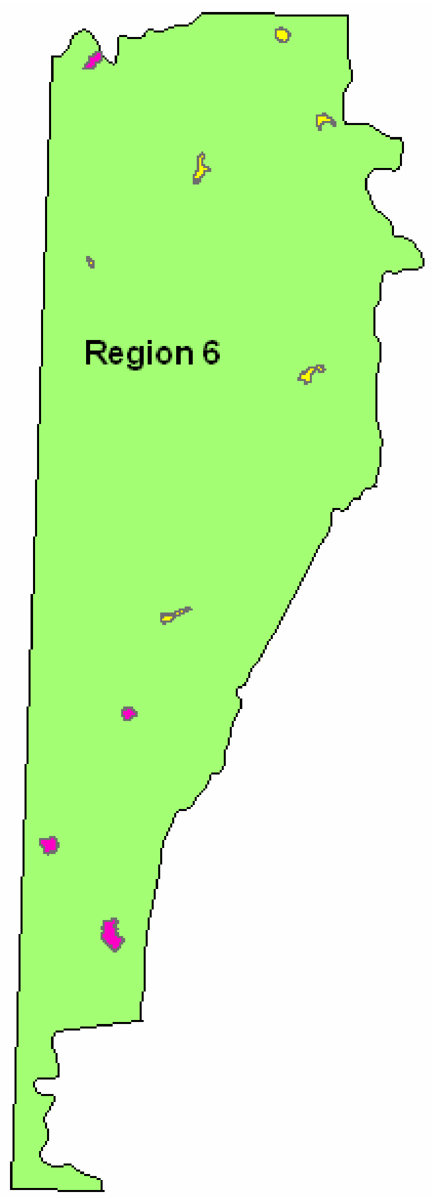


Figure 6-2: Region 6 Watershed Map

Given the size of Region 6, more watersheds would need to be investigated before any concrete conclusions can be drawn. From the available data, however, it appears that there is some correlation between watershed location, and the output data. This correlation could most likely be attributed to the "goodness of fit" of the USGS regression equations. There is only one regression equation per return-period that is applied to the greater part of the western half of the state of Utah. It is quite possible that the regression equations do not fit as well in some areas of the region.

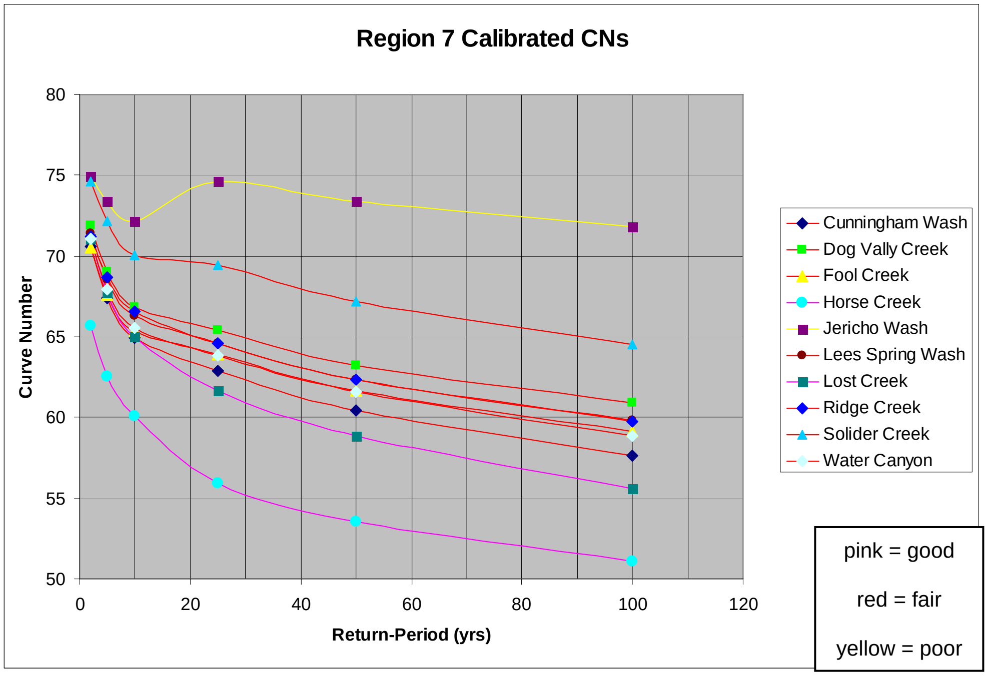


Figure 6-3: Region 7 Data Analysis

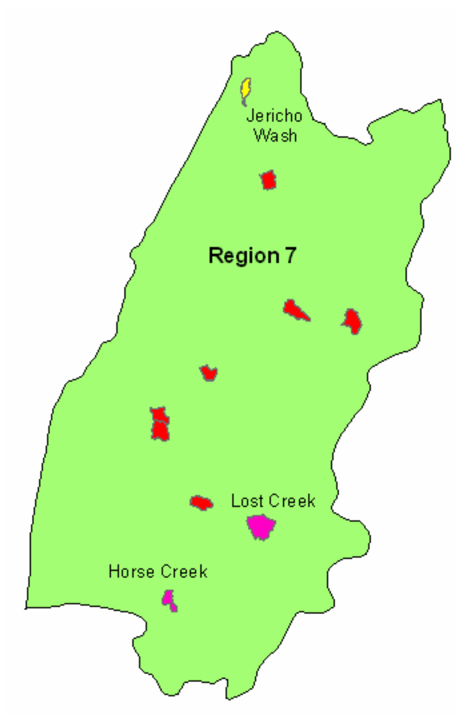


Figure 6-4: Region 7 Watershed Map

Region 7 and Region 9 also contained some data abnormalities. Region 7 in general produced good results. There is some inclination at the 25-year return-period for the Curve Number to jump up and then continue decreasing. The more abnormal results came from the "Jericho Wash" watershed as seen in yellow in Figure 6-3 above. The most reasonable results came from the "Lost Creek" and "Horse Creek" watersheds. The relative locations of these watersheds are shown in Figure 6-4. Again it seems that the abnormalities in the data are location based. The best fitting data occurred in the watersheds at the southern end of the region and the less typical data occurred in the farthest north watershed. The clusters of good fitting data also appeared in Region 9 as seen in Figure 6-5 and Figure 6-6.

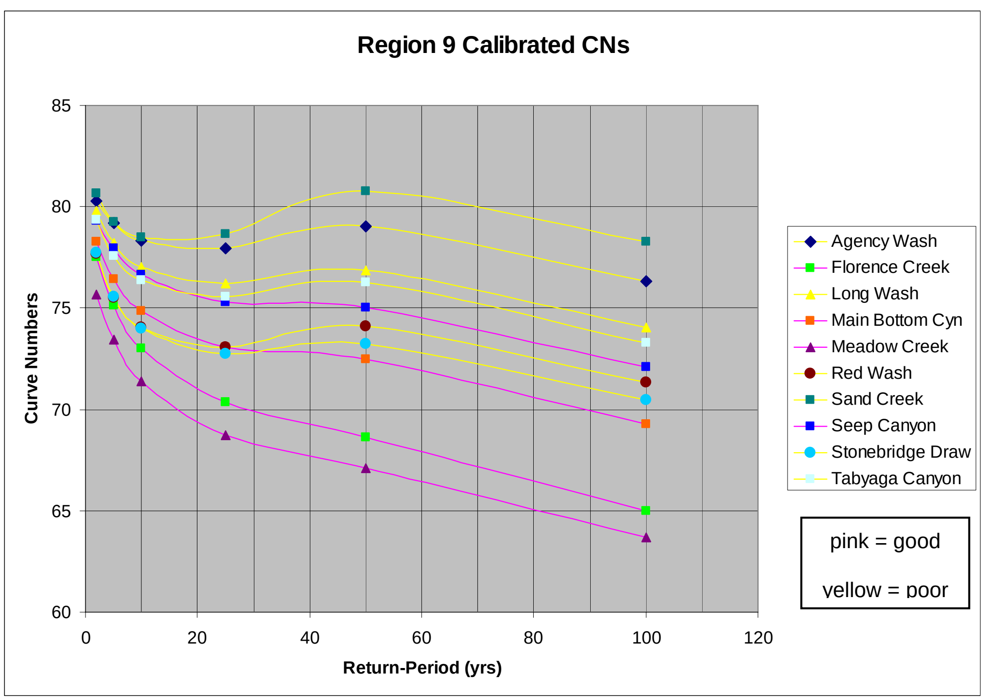


Figure 6-5: Region 9 Data Analysis

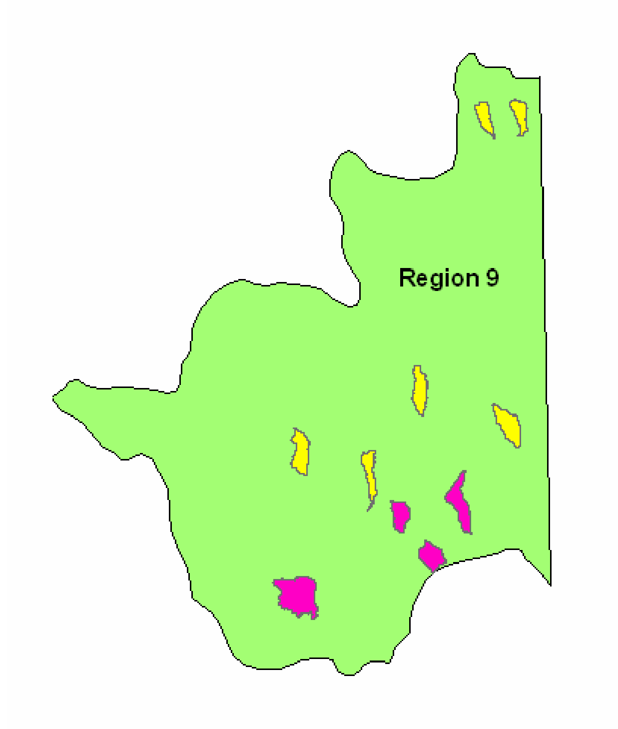


Figure 6-6: Region 9 Watershed Map

Similar to the Region 7 results, the data in Region 9 tends to jump up at the 50-year return-period and then continue its' decent as the return-period increases. This jump in the data could either be due to the regression equations predicting too much runoff or the NOAA rainfall grids predicting too little rainfall at the 50-year return-period and beyond.

To further explore the unexpected data of Region 8, the CN calibrations for the watersheds in Region 8 were also processed using the neighboring Region 7 equations. The Region 7 equations were considered appropriate for use within Region 8 based on observations in past studies (Nelson 2008). When using Region 7 equations the typical trend of decreasing CN with increasing return-period as seen in Figure 6-7 was more prominent. The return of this trend suggests possible error in Region 8 regression equations.

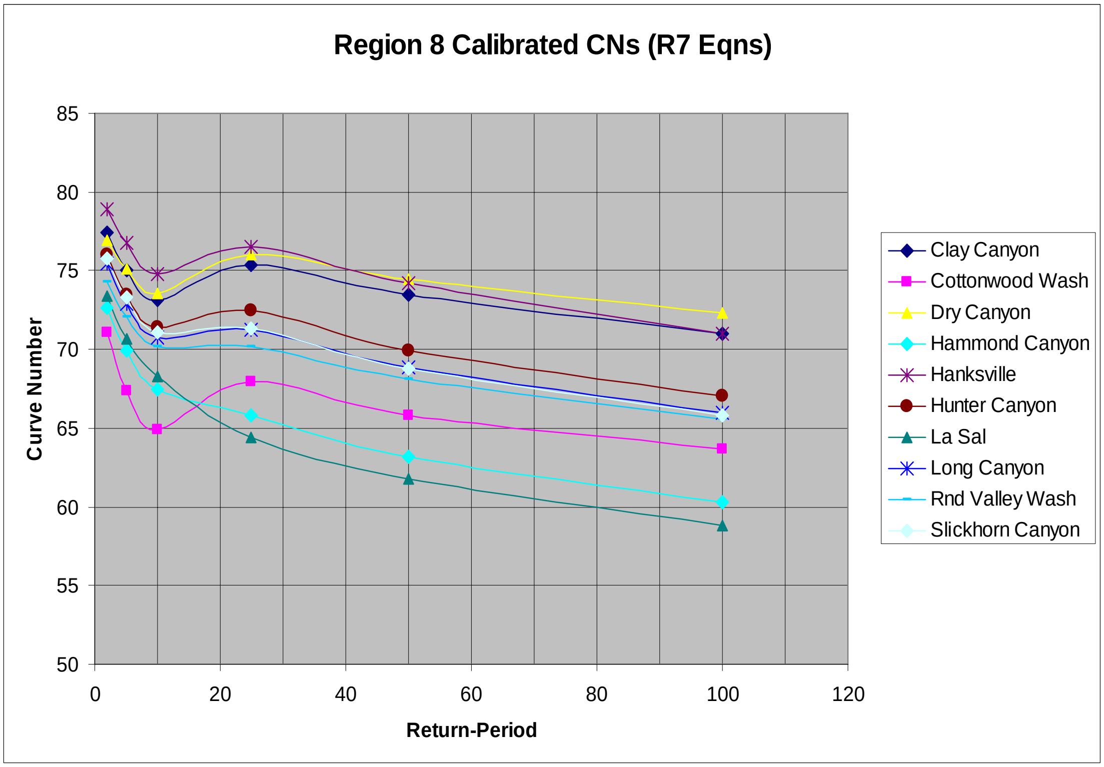


Figure 6-7: Region 8 Calibrated CN Graph using Region 7 Equations

The presence of regional trends as well as trends within regions was quite strong. The Region 4 results were exceptional and were as expected. Results for Region 7 and 9 were quite good, but contained unanticipated hump in the data. Results for Region 6 were mostly good, but the results for Region 8 and some of Region 6 were less than satisfactory. It is not surprising that results for Region 4 were very good. Region 4, as discussed previously, is the more populated area in the state. More abundant and better data would be expected in these areas and result in better interpolations and regression equations. Region 6 and Region 8 are so large that it would be difficult to fathom that one set of regression equations would be sufficient to characterize the runoff in every location for the entire region. The regression equations that were used in this study are not the most recent generation of regression equations. As mentioned in 2.2.4, in October 2007, the USGS introduced a new set of improved regression equations. Given the variety of results obtained in this study, application of the more recent regression equations is suggested.

6.2 Calibration for UDOT CN Table

Research of CN calibration using the USGS regression equations began with a request from UDOT for a consistent, return-period based CN table that is appropriate for application in the state of Utah. With the research completed thus far some suggestions can be made for the improvement of the UDOT CN table. Table 6-1 is a summary of the weighted average scalars developed in Chapter 5.

Table 6-1: Scalars for UDOT CN Table Calibration

REGION	WEIGHTED AVERAGE SCALAR					
	2YR	5YR	10YR	25YR	50YR	100YR
4	1.09	1.05	1.01	0.95	0.91	0.86
6	-----	0.98	0.96	0.95	0.95	0.97
7	0.99	0.95	0.92	0.89	0.86	0.82
8	1.07	1.04	1.01	1.01	0.97	0.93
9	1.17	1.14	1.12	1.10	1.10	1.05

This table contains the multipliers that UDOT could use to transform composite CNs derived from the use of their CN table to the USGS regression equation calibrated CN for each return-period. These scalars were calculated for each watershed at each return-period by dividing the calibrated CN by the composite CN that was calculated using the UDOT CN table. The values in Table 6-1 are all fairly close to 1 which indicates that the CN values currently used by UDOT are fairly close to those calibrated using the USGS equations. After reviewing this table some regional trends become obvious. The UDOT composite CNs in Region 4 appear to be appropriate for the 10-year return-period (i.e. the scalar is close to 1) but should be adjusted when designing for a higher or lower return-period as indicated in the table. In Regions 6 and 7, the UDOT CNs were consistently high on average when compared to the regression equation calibrated CNs. The UDOT CNs in Regions 8 and 9 were consistently low on average. For improved scalars, a greater number of watersheds should be included in the weighted average and should be calibrated using the more recent regression equations.

7 Conclusions

CN calibration using the USGS regression equations proved to be quite consistent when compared to calibrations obtained using measured data. Further comparisons to calibrations using gauged data should be pursued to ensure the accuracy of this method in all regions. The use of this method in large NFF regions should also be further investigated to ensure consistent results.

Although the CNs calibrated through the use of the USGS regression equations inherit the weaknesses of assumptions and estimations made in the development of the regression equations and design hydrograph, the use of USGS regression equations is generally an appropriate method of CN calibration. This method of CN calibration would be especially useful in cases where calibration is needed on a large scale or when gauged data are unavailable. It is simple, consistent in smaller NFF regions and uses design principles that are common and familiar in industry. Use of the USGS regression equations in calibration provides CNs that are not only calibrated for local application, but are also indexed by return-period, which would be useful for design purposes. While this study was completed for just the state of Utah, the method of CN calibration using the USGS regression equations could be applied in any region in the United States.

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Appendix A. CN Table Currently used by UDOT

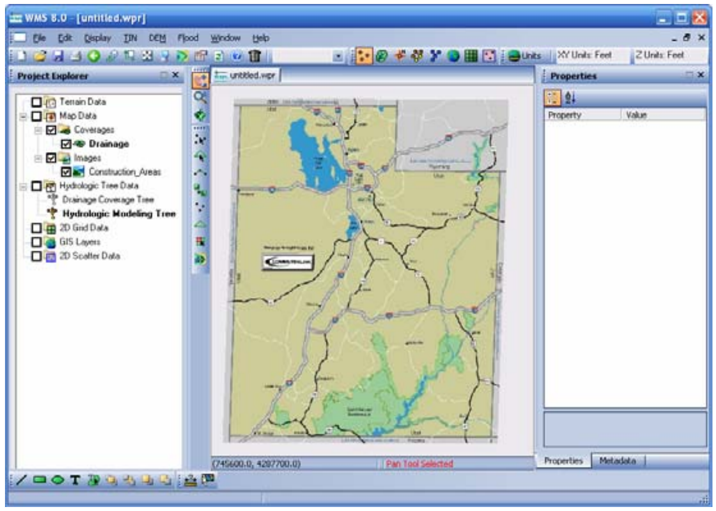
Table A-1: UDOT CN Table (Dyer 2006)

		Soil Type			
LUCODE	**Description**	**A**	**B**	**C**	**D**
11	Residential	61	75	83	87
12	Commercial Services	89	92	94	95
13	Industrial	81	88	91	93
14	Transportation Communication	98	98	98	98
16	Mixed Urban or Build-Up Land	75	85	88	98
21	Cropland and Pasture	72	81	88	91
22	Orchards Groves Vineyards Nurseries	62	73	80	85
31	Herbaceous Rangeland	39	61	84	89
32	Shrub and Grass Rangeland	45	66	86	90
33	Mixed Rangeland	72	79	86	92
34	Sagebrush with understory	45	51	68	78
35	Desert Shrubs	50	68	80	86
41	Deciduous Forest Land – Oak and Aspen (80%)	25	32	42	52
42	Evergreen Forest Land	36	60	73	79
43	Mixed Forest Land	36	60	73	79
44	Pinion - Juniper	45	53	75	80
51	Streams and Canals	0	0	0	0
52	Lakes	0	0	0	0
53	Reservoirs	0	0	0	0
54	Bays and Estuaries	0	0	0	0
61	Forested Wetlands	30	55	70	77
62	Nonforested Wetlands	30	58	71	78
71	Dry Salt Flats	74	80	90	92
72	Beaches	50	50	50	50
73	Sandy Areas and Other Beaches	63	77	85	88
74	Bare Exposed Rocks	98	98	98	98
75	Strip Mines, Quarries, and Gravel PIts	77	86	91	94
77	Mixed Barren Lands	77	86	91	94
86	Mixed Rocky – Sparse Junipers	78	87	95	98
87	High Planes	65	69	73	77
91	Perennial Snowfields	0	0	0	0
92	'Glaciers"	0	0	0	0

Appendix B. Outlined Calibration Process in WMS

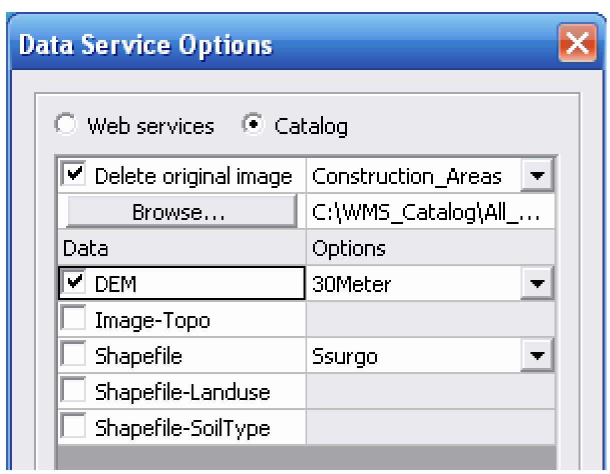
CN CALIBRATION PROCESS IN WMS (Dyer 2006)

1. Open Construction_Areas.jpg (digital map of the state of Utah)



2. Choose your watershed and outlet location (coordinates for student projects are found in the “Station Pairs Worksheet.xls”)
3. Use the “Get Data Tool”

   a. Drag a box around the watershed to acquire DEM
   b. When the box pops up click the Catalog option
   c. Browse for the Catalog
   d. Check the DEM box



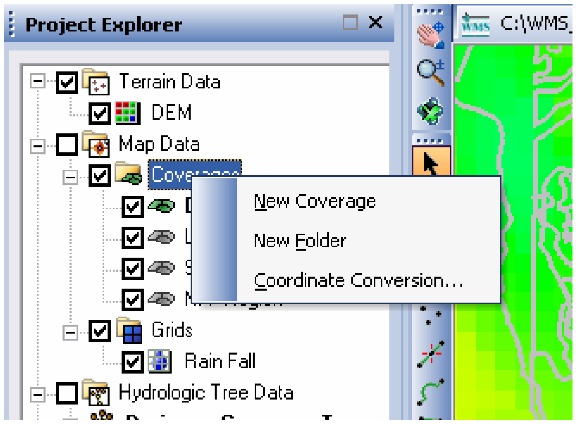
4. Click “DRAINAGE MODULE TOOL”
   a. DEM>Compute Topaz (choose units, click ok)

5. Create an Outlet at the correct coordinates

6. DEM>Delineate Basins Wizard (Click Ok, choose Consistent Units, Click Ok)

7. Optional: DEM>Delete Null Basin Cells Data

8. Right Click on “Coverages” Create New Coverage



   a. Make the coverage a “Land Use” coverage

9. Making sure the new land use coverage is highlighted use the “Get Data Tool”

   a. Drag a box around the watershed to acquire Land use

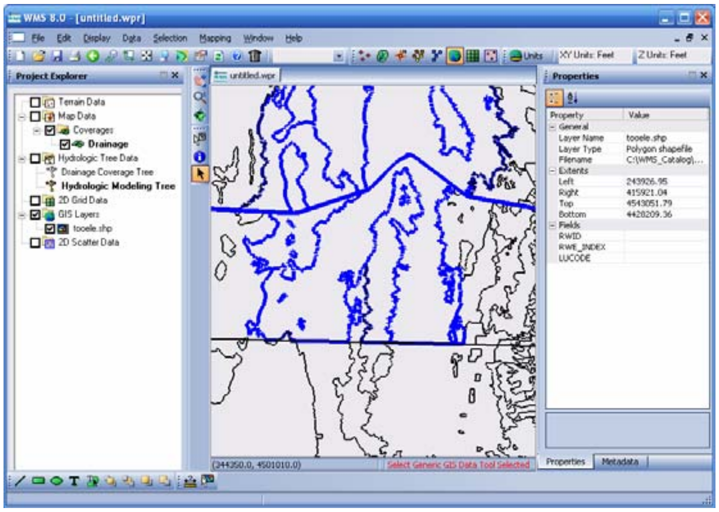
   b. When the box pops up click the Catalog option

   c. Browse for the Catalog

   d. Check the Shapefile- landuse box

10. Using the GIS MODULE TOOLS click the “Select Shapes Tool”

11. Drag a box around the watershed (some shapes should turn blue)



12. Mapping>shapes->feature objects. Next, Next, Finish

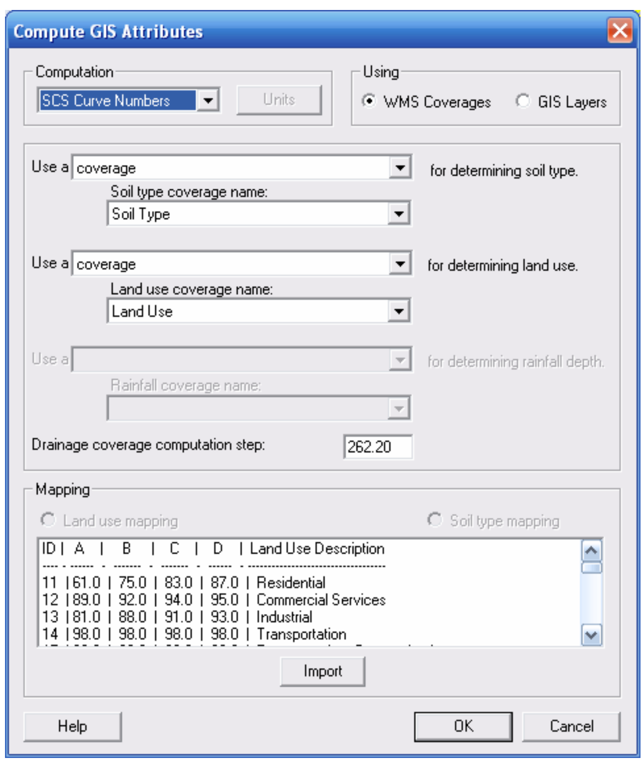
13. Repeat STEPS 8-12 creating a “SOIL TYPE COVERAGE”

14. Using the “HYDROLIC MODELING MODULE”

    a. Calculators>Compute GIS attribute

    b. SCS CN

        i. Import Class Mapping table click OK



        ii. Record CN Number

iii. Repeat with UDOT mapping table

iv. Record CN number

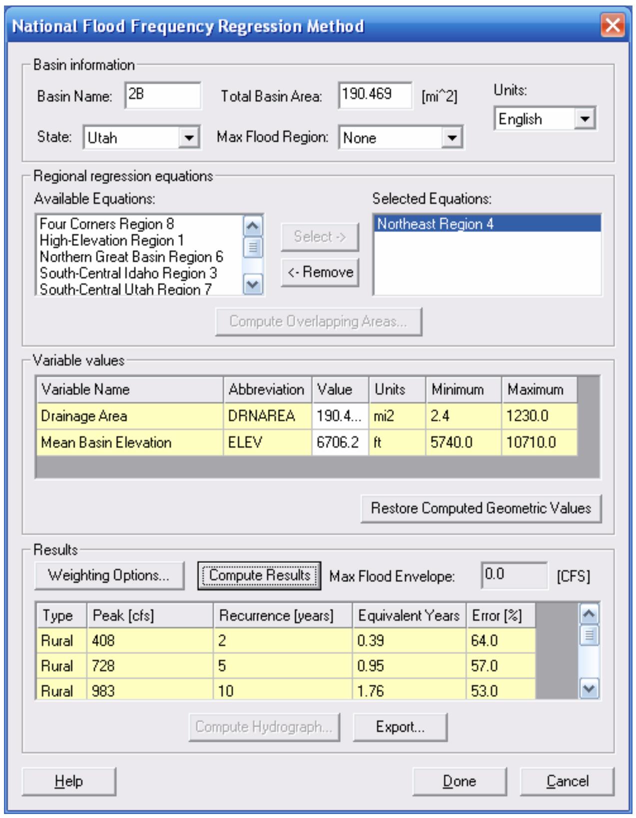
15. Right Click on “Coverages” Create New Coverage

a. Make the coverage a “NFF” coverage

b. Import the NFF regions map

16. Convert coordinates (geographic NAD 83 > UTM NAD 83)

17. Using the “HYDROLIC MODELING MODULE” Change the model type in the drop down box to “NFF”



18. Double click on the Basin

a. Make sure all the information was imported to your NFF model

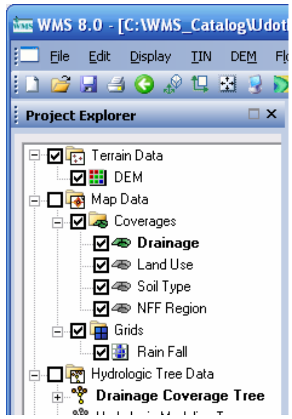
i. Ie. the NFF region and the basin areas etc.

b. Compute results (record results)

c. Compute hydrographs (record)

i. Use the Denver Method

19. Open Rainfall depth grid (make sure there extension is .grd so the Program gives you the option to import as a "rainfall depth grid"



Notice the 4 coverage's and the rainfall depth grid

a. Open HEC-1 script>precipitation to see the calculated value

b. Divide the computed number by 1000 to obtain the rain fall depth in inches.

c. Record data in spread sheet

d. Results will automatically be calculated for CN.

Appendix C. Class Average CN Table

Table C-1: Class Average CN Table

Class Average CN Table					
LUCODE	**Description**	**Soil Type**			
		A	**B**	**C**	**D**
11	Residential	60	74	82	87
12	Commercial Services	89	92	94	95
13	Industrial	81	88	91	93
14	Transportation and Communication	76	85	89	91
16	Mixed urban or built up land	77	85	90	93
17	Other urban or built up land	71	82	88	90
21	Cropland and Pasture	49	68	78	84
22	Orchards, Groves, Vineyards, Nurseries	47	67	77	83
23	Confined Feeding Operations	55	63	66	68
24	Other Agricultural Land	62	74	82	86
31	Herbaceous Rangeland	45	66	77	82
32	Shrub and Brush Rangeland	44	64	77	82
33	Mixed Rangeland	46	66	77	83
41	Deciduous Forest Land	31	58	68	75
42	Evergreen Forest Land	35	59	73	79
43	Mixed Forest Land	39	61	74	80
52	Lakes	0	0	0	0
53	Reservoirs	0	0	0	0
61	Forested Wetlands	44	58	68	75
62	Non-forested Wetlands	32	55	68	75
74	Bare Exposed Rock	98	98	98	98
75	Strip Mines	71	80	85	88
76	Transitional Areas	69	78	84	88
81	Shrub and Shrub Tundra	60	74	83	87
82	Herbaceous Tundra	66	76	83	87
83	Bare Ground	74	83	87	90
85	Mixed Tundra	50	65	74	80

Appendix D. USGS Regression Equations by Region

Table D-1: Region 1 Regression Equations (USGS 1999)

Region 1		
Region Equation	**Average Standard Error of Prediction (%)**	**Equivalent years of record**
$Q_2 = 0.124AREA^{0.845}PREC^{1.44}$	59	0.16
$Q_5 = 0.629AREA^{0.807}PREC^{1.12}$	52	0.62
$Q_{10} = 1.43AREA^{0.786}PREC^{0.958}$	48	1.34
$Q_{25} = 3.08AREA^{0.768}PREC^{0.811}$	46	2.50
$Q_{50} = 4.75AREA^{0.758}PREC^{0.732}$	46	3.37
$Q_{100} = 6.78AREA^{0.750}PREC^{0.668}$	46	4.19

Table D-2: Region 3 Regression Equations (USGS 1999)

Region 3		
Region Equation	**Average Standard Error of Prediction (%)**	**Equivalent years of record**
$Q_2 = 0.444AREA^{0.649}PREC^{1.15}$	86	0.29
$Q_5 = 1.21AREA^{0.639}PREC^{0.995}$	83	.49
$Q_{10} = 1.99AREA^{0.633}PREC^{0.924}$	80	.77
$Q_{25} = 3.37AREA^{0.627}PREC^{0.849}$	78	1.23
$Q_{50} = 4.70AREA^{0.625}PREC^{0.802}$	77	1.57
$Q_{100} = 6.42AREA^{0.621}PREC^{0.757}$	78	1.92

Table D-3: Region 4 Regression Equations (USGS 1999)

Region 4		
Region Equation	**Average Standard Error of Prediction (%)**	**Equivalent years of record**
$Q_2 = 0.0405AREA^{0.701}(ELEV/1,000)^{2.91}$	64	0.39
$Q_5 = 0.408AREA^{0.683}(ELEV/1,000)^{2.05}$	57	.95
$Q_{10} = 1.26AREA^{0.674}(ELEV/1,000)^{1.64}$	53	1.76
$Q_{25} = 3.74AREA^{0.667}(ELEV/1,000)^{1.24}$	51	3.02
$Q_{50} = 7.04AREA^{0.664}(ELEV/1,000)^{1.02}$	52	3.89
$Q_{100} = 11.8AREA^{0.662}(ELEV/1,000)^{0.835}$	53	4.65

Table D-4: Region 6 Regression Equations (USGS 1999)

Region 6		
Region Equation	Standard Error of Regression (Log Units)	Equivalent years of record
$Q_2 = 0$	--	--
$Q_5 = 32AREA^{0.80}(ELEV/1{,}000)^{-0.66}$	1.47	0.233
$Q_{10} = 590AREA^{0.62}(ELEV/1{,}000)^{-1.6}$	1.12	0.748
$Q_{25} = 3{,}200AREA^{0.62}(ELEV/1{,}000)^{-2.1}$	0.796	2.52
$Q_{50} = 5{,}300AREA^{0.64}(ELEV/1{,}000)^{-2.1}$	1.1	1.75
$Q_{100} = 20{,}000AREA^{0.51}(ELEV/1{,}000)^{-2.3}$	1.84	0.794

Table D-5: Region 7 Regression Equations (USGS 1999)

Region 7		
Region Equation	Average Standard Error of Prediction (%)	Equivalent years of record
$Q_2 = 0.0150AREA^{0.697}(ELEV/1{,}000)^{3.16}$	56	0.25
$Q_5 = 0.306AREA^{0.590}(ELEV/1{,}000)^{2.22}$	45	1.56
$Q_{10} = 1.25AREA^{0.526}(ELEV/1{,}000)^{1.83}$	45	3.07
$Q_{25} = 122AREA^{0.440}$	49	4.60
$Q_{50} = 183AREA^{0.390}$	53	5.27
$Q_{100} = 264AREA^{0.344}$	59	5.68

Table D-6: Region 8 Regression Equations (USGS 1999)

Region 8		
Region Equation	Average Standard Error of Prediction (%)	Equivalent years of record
$Q_2 = 598AREA^{0.501}(ELEV/1{,}000)^{-1.02}$	72	0.37
$Q_5 = 2{,}620AREA^{0.449}(ELEV/1{,}000)^{-1.28}$	62	1.35
$Q_{10} = 5{,}310AREA^{0.425}(ELEV/1{,}000)^{-1.40}$	57	2.88
$Q_{25} = 10{,}500AREA^{0.403}(ELEV/1{,}000)^{-1.49}$	54	5.45
$Q_{50} = 16{,}000AREA^{0.390}(ELEV/1{,}000)^{-1.54}$	53	7.45
$Q_{100} = 23{,}300AREA^{0.377}(ELEV/1{,}000)^{-1.59}$	53	9.28

Table D-7: Region 9 Regression Equations (USGS 1999)

Region 9		
Region Equation	Average Standard Error of Prediction (%)	Equivalent years of record
$Q_2 = 0.0204AREA^{0.606}(ELEV/1{,}000)^{3.5}$	68	0.14
$Q_5 = 0.181AREA^{0.515}(ELEV/1{,}000)^{2.9}$	55	.77
$Q_{10} = 1.18AREA^{0.488}(ELEV/1{,}000)^{2.2}$	52	1.70
$Q_{25} = 18.2AREA^{0.465}(ELEV/1{,}000)^{1.1}$	53	2.81
$Q_{50} = 248AREA^{0.449}$	57	3.36
$Q_{100} = 292AREA^{0.444}$	59	3.94

NOTE:

AREA= Basin Area

PREC=Mean Annual Precipitation

ELEV=Mean Basin Elevation Above Sea Level

Appendix E. Centerville Creek and Coal Creek Data

<u>Centerville Creek Data</u>

Table E-1: Centerville Creek Data

Precipitation Gage:	Bountiful Val Verda, Davis County, UT					
Location (lat/long: d,m,s):	40	51	0	111	53	0
Stream Gage:	Centerville Creek near Centerville, UT					
Location (lat/long: d,m,s):	40	54	59	111	51	44
Date of Storm:	9/15/2002					
Basin Area (mi^2):	3.17					
Total Precipitation (in):	1.1					
Base Flow (cfs):	1					
Peak Flow (cfs):	2					
Runoff Volume (ft^3):	63270					
UDOT CN:	69.3					
Gaged CN:	69					

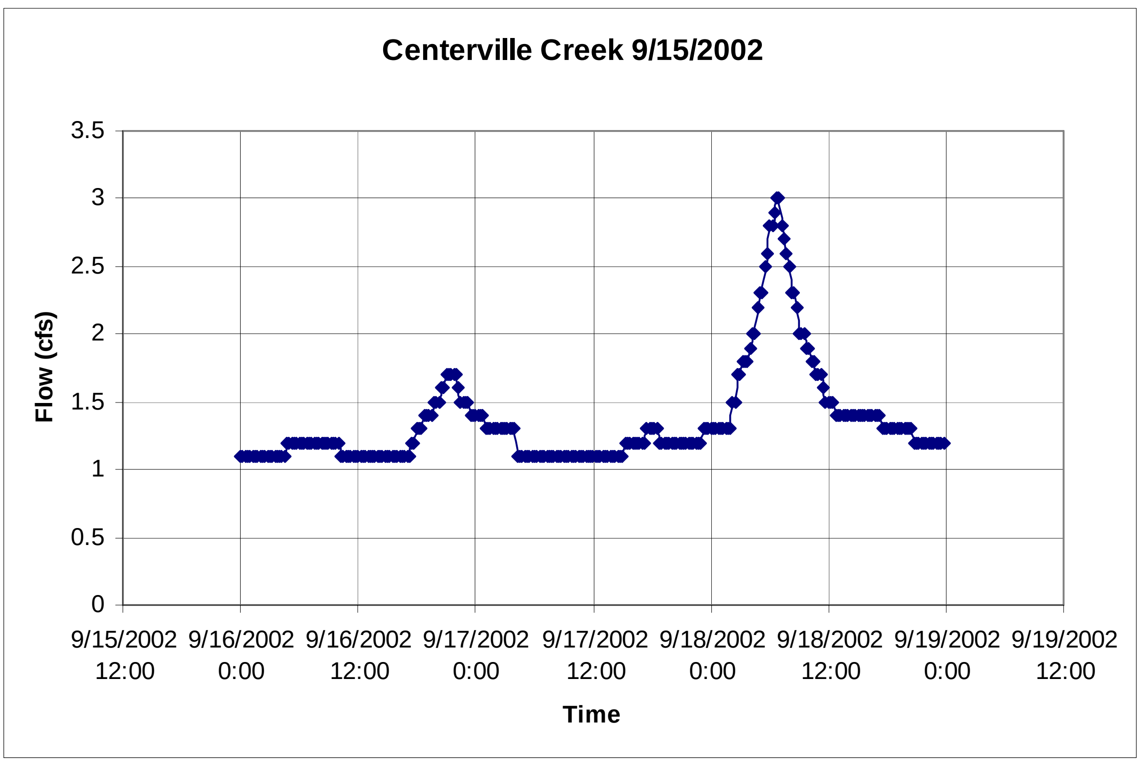


Figure E-1: Centerville Creek Hydrograph

Distance between stream and precipitation gauge: 5 miles

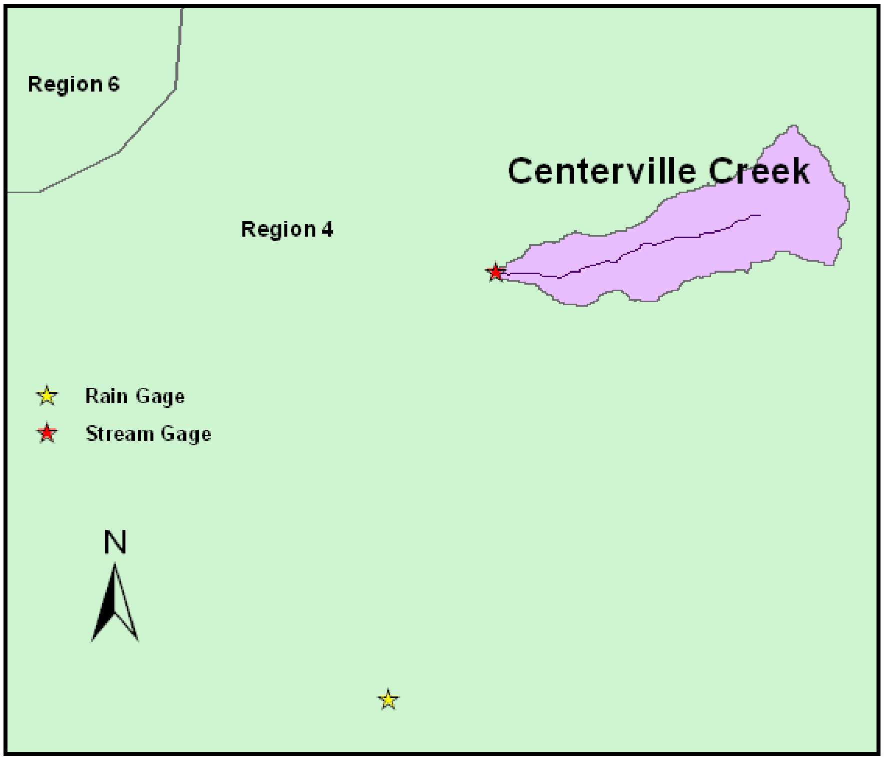


Figure E-2: Centerville Creek Gauge Map

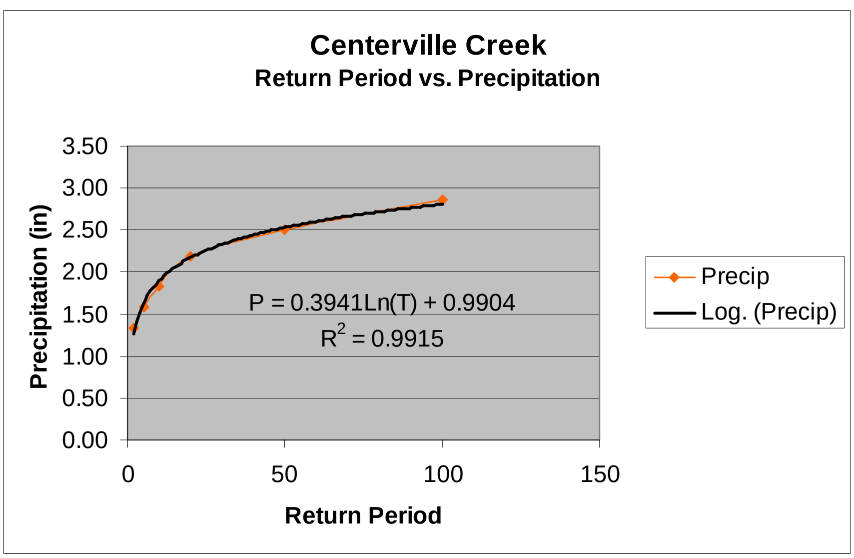


Figure E-3: Centerville Creek Equivalent Return-Period Graph

P = 1.1 inches so the equivalent return-period, T=1.3 years

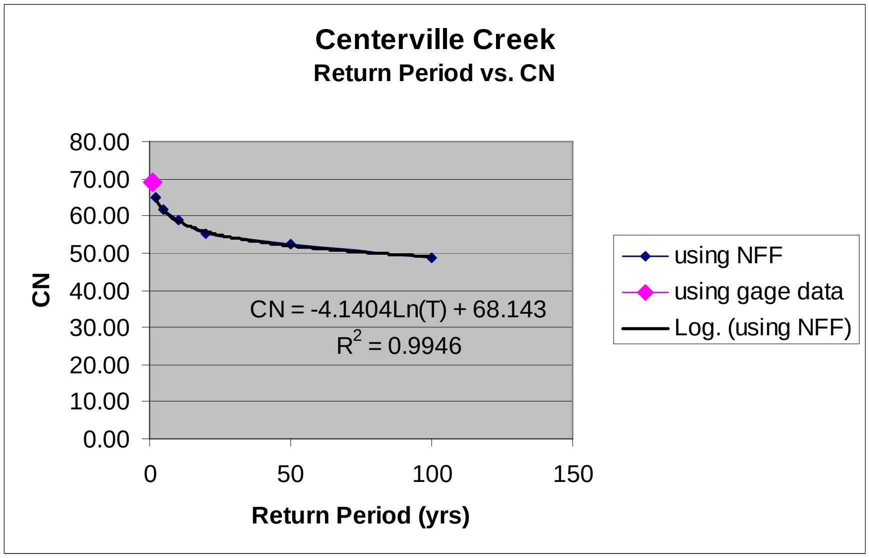


Figure E-4: Centerville Creek Equivalent CN Graph

T=1.3 so USGS regression equation calibrated CN=67.

Gauged CN=69.

2.9% decrease

Coal Creek Data

Table E-2: Coal Creek Data

Precipitation Gage:	Cedar City 5 E, Iron County, UT					
Location (lat/long: d,m,s):	37	39	0	113	0	0
Stream Gage:	Coal Creek near Cedar City, UT					
Location (lat/long: d,m,s):	37	40	20	113	2	2
Date of Storm:	8/23/1987					
Basin Area (mi^2):	77.77					
Total Precipitation (in):	1.3					
Base Flow (cfs):	14					
Peak Flow (cfs):	148					
Runoff Volume (ft^3):	6076000					
UDOT CN:	61.9					
Gaged CN:	69.1					

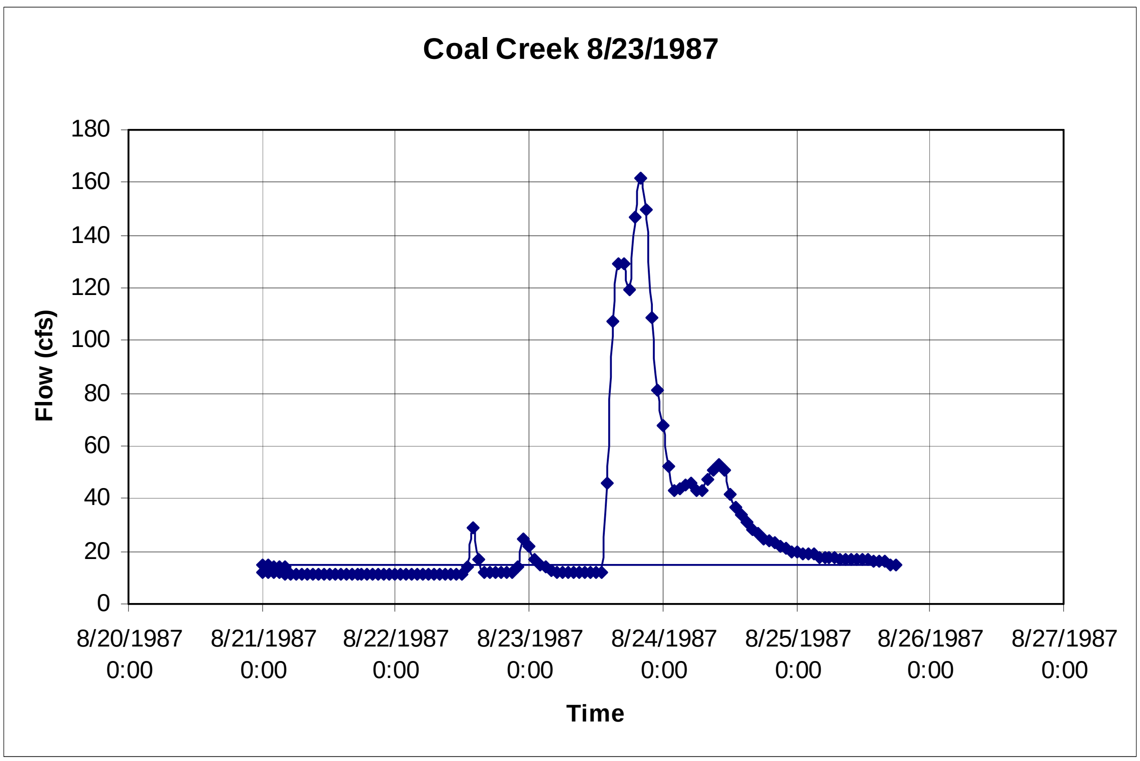


Figure E-5: Coal Creek Hydrograph

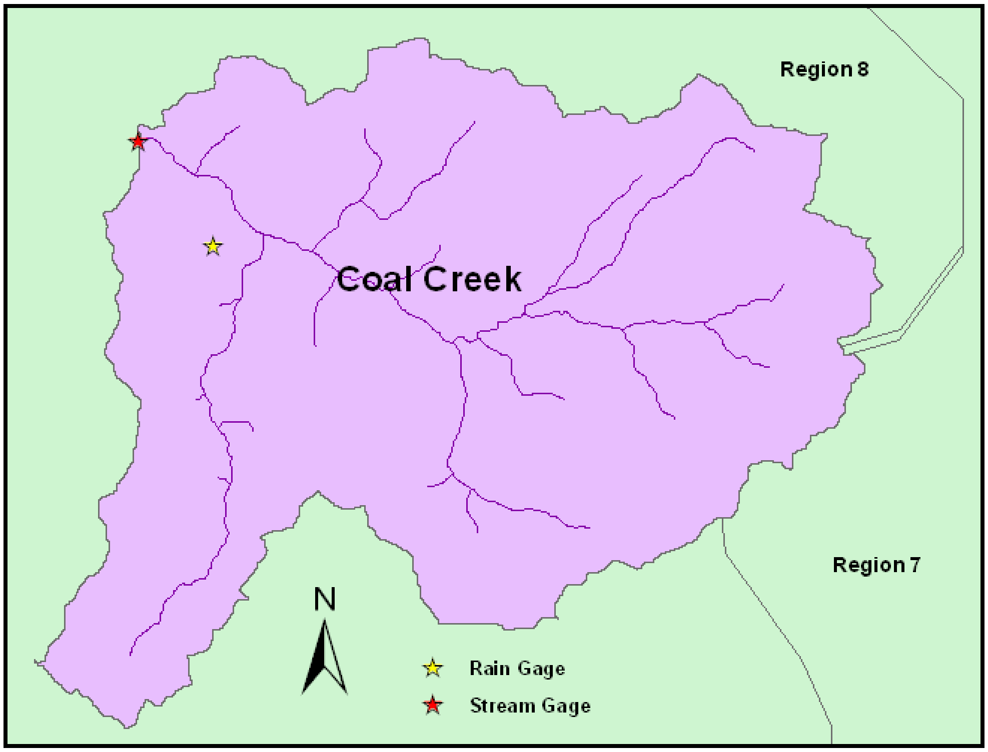


Figure E-6: Coal Creek Gauge Map

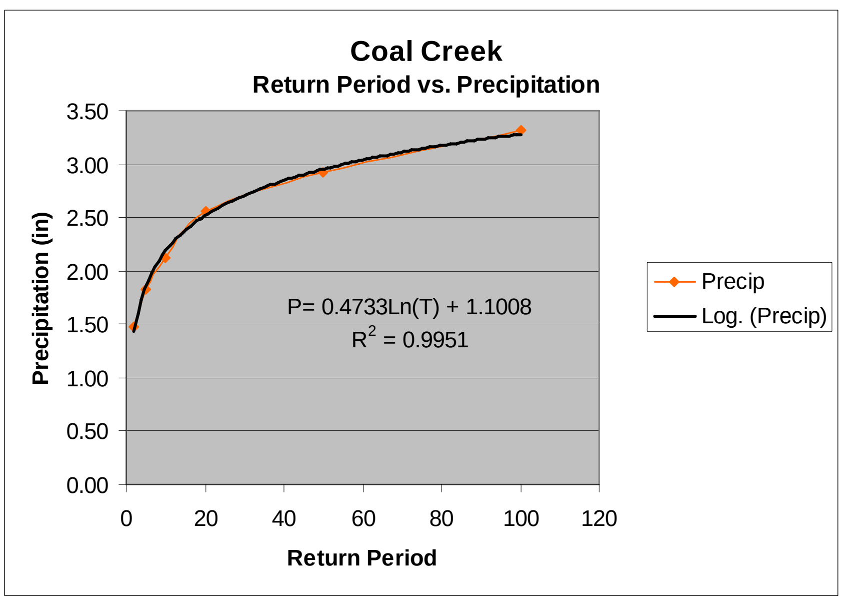


Figure E-7: Coal Creek Equivalent Return-Period Graph

P = 1.3 inches so the equivalent return-period is T=1.5 years

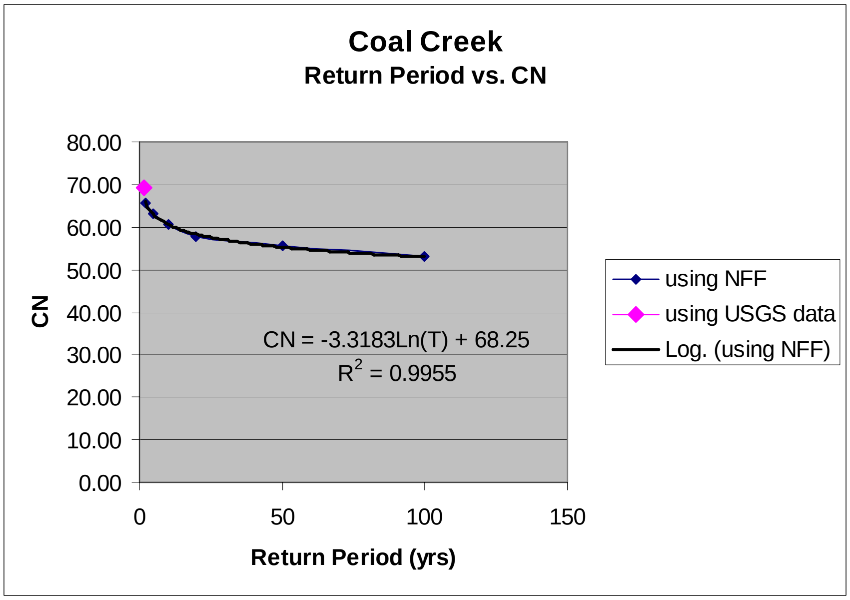


Figure E-8: Coal Creek Equivalent CN Graph

T=1.5 so USGS regression equation calibrated CN=66.9.

Gauged CN=69.1

3.3% decrease

Appendix F. Guide to Accompanying CD